Bulletin 23

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

STEAMING TESTS OF COALS

AND

RELATED INVESTIGATIONS

SEPTEMBER 1, 1904, TO DECEMBER 31, 1908

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

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By Joseph A. Holmes.

The establishment on July 1, 1910, of a National Bureau of Mines on a permanent basis, and the transfer, for continuance under this bureau, of the fuel investigations organized and conducted, 1904 to 1910, under the United States Geological Survey, were considered as making a suitable occasion for assembling and publishing in convenient form a description of those investigations, the methods followed, the equipment used, and the results obtained. The larger part of the data has been assembled for publication in three reports—the first (Bulletin 13) on the fuel tests made in gas producers, the second (Bulletin 23) on the fuels tested in boiler furnaces, and the third (Bulletin 22) giving the chemical analyses of the coals tested and a statement regarding the mines and beds from which these coals were collected.

Much of this material has already been published in various bulletins of the Geological Survey, but most of those bulletins are now out of print and much of the material has not yet been published. Hence, it is deemed wise to bring together all the information, both published and unpublished, that may have special value and to publish it in convenient form. A résumé of certain additional data covering the briquetting, coking, and other miscellaneous uses of the fuels tested will be similarly segregated and published in a future bulletin of the Bureau of Mines.

When Congress authorized this work in 1904, the Director of the United States Geological Survey placed its supervision under a committee consisting of E. W. Parker and M. R. Campbell, of the Geological Survey, and the present writer; and this committee selected as its consulting experts Prof. Robert H. Fernald, of the mechanical-engineering department of Washington University, St. Louis, to take charge of the gas-producer investigations; Prof. Lester P. Breckenridge, of the mechanical-engineering department of the University of Illinois, to take charge of the boiler and steaming investigations; and Prof. Nathaniel W. Lord, of the chemical department of the University of Ohio, to take charge of the chemical work.

In planning the fuel investigations, the committee found that there were limitations as to equipment available; no satisfactory methods had been developed; and few experts had been adequately trained for such investigations. Nevertheless, it was believed that, if prop-

erly carried on, the results of these investigations would have a large and permanent value. Therefore, the coals used in the investigations were selected and collected in such manner as to insure their being representative of actual and extensive resources.

During 1905 and subsequent years the administrative supervision of these investigations was assigned by the Director of the Geological Survey to the present writer, but the technical advice of Profs. Lord, Breckenridge, and Fernald has been followed throughout, and the administrative plans developed during the work of 1904 so largely by Messrs. Parker and Campbell, with whom the writer was associated, have continued to serve as a general guide.

STEAMING TESTS OF COALS

AND

RELATED INVESTIGATIONS

SEPTEMBER 1, 1904, TO DECEMBER 31, 1908

By L. P. Breckenridge, Henry Kreisinger, and Walter T. Ray.

INTRODUCTION.

HISTORY AND OBJECT OF FUEL-TESTING PLANT.

The investigations of fuels conducted by the technologic branch of the United States Geological Survey had their inception at the Louisiana Purchase Exposition in 1904. By an act approved February 18, 1904, Congress authorized the work of analyzing and testing at the Louisiana Purchase Exposition the coals and lignites of the United States, under the supervision of the Director of the United States Geological Survey. An appropriation of $30,000 was made for this purpose. In the general deficiency bill dated April 27, 1904, the sum of $30,000 was added to the appropriation.

To carry out these investigations the Director of the Geological Survey appointed a committee consisting of E. W. Parker, statistician of the Geological Survey; Joseph A. Holmes, State geologist of North Carolina; and Marius R. Campbell, a geologist of the Geological Survey.

Under the first act authorizing this work all of the machinery and coal for the tests was to be furnished the Government free of charge. The buildings containing the testing apparatus were all paid for out of the first appropriation. After the close of the Louisiana Purchase Exposition every Congress made an appropriation for continuing these fuel tests. These subsequent appropriations permitted the purchase of appliances better adapted for the testing work.

The general object of these investigations as they were started at St. Louis was to determine the fuel value of the coals and lignites of the United States in the following ways:

(*a*) By chemical analysis.

(*b*) By burning under boilers.

(*c*) By burning in the gas producer and using the gas for power generation.

(*d*) By briquetting and burning the briquets under stationary, marine, and locomotive boilers.

(*e*) By coking to determine the coking qualities.

(*f*) By testing after washing a coal that was originally high in ash.

To do this work the plant was equipped with a chemical laboratory for coal analysis, 2 Heine water-tube boilers of 210 boiler horsepower each set up over hand-fired furnaces, 1 Taylor pressure gas producer with auxiliaries, 2 briquetting machines, 3 beehive coke ovens, and a washery with two jigs. The various departments of the plant were connected with coal conveyors to facilitate the handling of coal.

About a year after the close of the exposition all the buildings had to be cleared away from the fair grounds. This made it necessary to move the fuel-testing plant. Accordingly, early in 1907 most of the departments of the plant were removed to the Jamestown Exposition at Norfolk, Va., where a large building was provided for the continuation of the fuel tests during the exposition. It was felt at the time that it was highly desirable to make steaming and briquetting tests of the coals which reach Norfolk, Va., for the use of the United States Navy and the merchant marine.

As the coking qualities of the coals of the eastern fields were fairly well known, it was thought advisable that the washing and coking sections should investigate the coals of the Rocky Mountain region and determine their fitness for producing high-grade coke for metallurgical purposes. Consequently these two sections were removed to Denver, Colo.

The main chemical laboratory was moved to Pittsburgh, which appeared a convenient location for it inasmuch as samples of coal for chemical analysis were to be collected and shipped from every coal field in the United States.

At the close of the Jamestown Exposition the steaming, gas-producer, and briquetting sections of the fuel-testing plant were moved to Pittsburgh, and were installed in the arsenal buildings of the United States War Department, where these divisions are continuing their experiments.

The coal washery and the coke ovens at Denver, Colo., were dismantled in the fall of 1908, the investigations being discontinued for the time.

GENERAL STATEMENT OF THE WORK DONE BY THE STEAM-ENGINEERING SECTION.

From the beginning of the fuel-testing work at St. Louis to the end of the year 1908 the steam-engineering section has made the following tests and investigations:

(*a*) A series of 501 steaming tests under Heine stationary boilers on 180 different coals coming from 24 different States; some of these tests were made at St. Louis, Mo., others at Norfolk, Va.

(*b*) A series of 21 steaming tests with briqueted and run-of-mine coal under a Normand marine boiler on the U. S. torpedo boat *Biddle*, at the Norfolk Navy Yard.

(*c*) A series of 14 steaming tests with briqueted and run-of-mine coal in a locomotive boiler at the yards of the Seaboard Air Line Railway, at Portsmouth, Va.

(*d*) A series of 15 steaming tests with North Dakota lignite in a furnace of the semigas-producer type, under a Stirling boiler, at the United States irrigation plant, at Williston, N. Dak.

(*e*) A series of about 300 laboratory tests with small multitubular boilers for the purpose of studying their heat-absorbing properties.

(*f*) A series of experiments with laboratory apparatus for the purpose of studying the relation of the pressure drop through fuel beds and boilers to the weight of gases flowing through them. These experiments were supplemented by the investigation of data obtained with large boilers in actual operation.

Of the above only the tests under (*a*) are considered in full detail in this bulletin. Tests under (*b*), (*c*), (*d*), (*e*), and (*f*), respectively, have been described fully in United States Geological Survey Bulletins 367, 403, and 412, and in Bureau of Mines Bulletin 2 and Bulletin 18, the latter being now in course of publication. However, a brief summary of these tests is presented in the second part of this bulletin under the caption "Résumé of special plant and field investigations."

SCOPE OF THIS BULLETIN.

This bulletin is divided into two distinct but related parts.

Part I contains complete final data and results of all steaming tests made at the fuel-testing plant, a description of the plant and appliances, and a statement of the method of conducting and computing the tests. This part is intended for those who wish to study the details of the tests and make their own comparisons and deductions, and for those who wish to inform themselves as to the composition of the different coals and the results that may be expected from burning them in a hand-fired furnace.

Part II contains principally an analytical study of the tests reported in Part I. In this study a great many comparisons of classified tests

are made and deductions are drawn. This part is intended for the busy engineer who has not time to study the tests for himself. Part II also contains a brief account of tests made outside the plant and of special investigations made to clear up certain features in the problem of steam generation. In this account the investigations on the transmission of heat in boilers and the experiments on the flow of gases through fuel beds and boilers are particularly mentioned. The account of these investigations is followed by a discussion of the fundamental principles of the combustion of coal, transmission of heat, and the movement of gases through boiler settings.

PART I.

DESCRIPTION AND COMPLETE FINAL DATA OF STEAMING TESTS.

OBJECT OF STEAMING TESTS.

The primary object of the first 78 steaming tests made at the St. Louis plant during the Louisiana Purchase Exposition was to determine the comparative value of coals from the various coal fields of the country when used under boilers. The time available for testing was short and the coals to be tested were many. Consequently, only one steaming trial was made with each coal, unless because of some accident the trial was thought unreliable, in which case it was repeated. Thus 78 tests covered 75 different coals. Inasmuch as the coal came from fields so widely separated, it was rightly expected that its nature and its behavior on the grate would vary greatly. For this reason the testing boilers were equipped with hand-fired furnaces and plain grates, an equipment which, although not best fitted for some coals, would make possible the burning of all the coals. On this account the results obtained are not absolute, and are approximately comparative only for the hand-fired, tile-roof type of furnace. Nevertheless, the results of the tests furnish valuable indications of what the results would be in other types of furnaces and with other methods of stoking. This is particularly true of some of the western coals just coming into the market.

Although the tests were made carefully, the results in some cases are not the best that can be obtained in this type of furnace. The work could not be so arranged that all coals from the same locality could be tested on successive days. Coal from West Virginia was tested one day and lignite from North Dakota the next. This made it difficult for the man in charge of the firing to decide at the outset what method of burning was best adapted to each particular coal. Notwithstanding these unfavorable features, the over-all efficiency was generally fairly high, which speaks well of the efforts of the men managing the fires.

Efforts were also made to have all the coals of a uniform size when fired, but generally it was not possible to do this. The samples of coal to be tested were received as "run of mine"; after reaching the plant they were run through a crusher which was set to reduce the coals to a standard size. Some of these coals were brittle and

crumbled easily during the process of unloading, crushing, and conveying, so that they contained greatly varying percentages of slack when they reached the boiler room. All these undesirable but inherent features of the problem of testing fuels made it difficult, if not impossible, to obtain unquestionably comparative results from the steaming tests.

Soon after the close of the Louisiana Purchase Exposition it was decided to continue the fuel tests at the St. Louis plant. To avoid some of the above-mentioned objections and to make the results of the steaming tests more comparable, provision was made for testing larger samples of coal, so that it would be possible to make three or four steaming tests with each coal, each test being run at different rates of combustion. Furthermore, to provide for more economical burning of the coals, particularly of some of the western ones high in ash, one of the Heine boilers was equipped with a McClave rocking grate. A small cylindrical screen was purchased, which permitted the accurate determination of the percentage of the various sizes of the coal as burned. Several recording instruments were added to the equipment, so that more complete data could be obtained on which to base more thorough comparative studies of the steaming qualities of the coals. Although the equipment for making comparative tests was not an ideal one, nevertheless it was as good as could be selected for such widely variable conditions.

The object of the steaming tests made at the Norfolk plant was to study the relative economy of coals coming chiefly from the New River field, West Virginia, when burned under a boiler in a hand-fired furnace and when fired by a Jones underfeed stoker. A further object was to compare the values of these coals for making steam when in the run-of-mine condition and when compressed into two sizes of briquets. The steam plant was equipped for this purpose with the above-mentioned Heine boilers set up with a standard hand-fired furnace and a Jones underfeed stoker.

THE COALS TESTED.

The coals tested at the St. Louis plant came from the important coal fields of the country; those tested at the Norfolk plant came only from Virginia and West Virginia.

To be certain that the coal shipped to the plant represented the average product of the mine, or the average of a certain grade that it was desired to test, the coal was loaded at the mine into the railroad car under the supervision of a representative of the fuel-testing plant. This representative visited the mine a day or two previous to the loading of the coal, and studied the condition of mining and the treatment of the coal as it went from the mine to the car. He watched carefully the loading of the car, so as to prevent any

undue picking or any other irregularity that would make the coal better than the average output of the mine. In certain cases where cars were in the yard, already loaded with what was regarded as representative coal, one of these cars was selected at random and shipped to the testing plant.

Ordinarily the coal was sent to the plant in open cars without any protection from the weather, but such lignitic coals as would be much affected by weather in transit were loaded in box cars. Usually several weeks elapsed between the mining and the testing of the coals. The coal was sampled at the plant as it was being unloaded from the car into the bins. This sample was called the car sample. The coal was again sampled as it was burned, and the sample thus obtained was called the boiler-room sample. The analyses of these two samples varied appreciably, showing that coal from different parts of a car may vary in chemical composition. This is particularly true of coal from the bottom and from the top of a car. In transportation, fine coal and impurities are apt to find their way to the bottom of the car. The average weight of a carload of coal was about 40 tons; the average weight of the coal burned in a steaming test was 5 tons. The analyses varied according to whether a 5-ton lot was taken from the top or bottom of a car, or the top or bottom of a storage bin.

The supervision of the loading of the coal into the cars at the mines was done by the members of the field division, which was at first in charge of M. R. Campbell and later was under the direction of J. S. Burrows.

PERSONNEL.

The fuel tests made by the steam-engineering division of the fuel-testing plant were conducted under the direction of L. P. Breckenridge, then professor of mechanical engineering at the University of Illinois, and now holding a similar position at the Sheffield Scientific School, Yale University. The first 78 tests were made under the direct supervision of D. T. Randall. All succeeding tests were made under the direct charge of W. T. Ray. The crew conducting the tests consisted of six to ten observers and computers and a chemist. The following men were at various times members of the crew: H. Kreisinger, H. W. Weeks, L. R. Stowe, R. H. Kuss, I. I. Harman, H. B. Dirks, W. M. Park, G. S. Pope, R. W. Rutt, C. H. Green, R. H. Post, F. J. Bird, C. Fletcher, R. Galt, C. E. Augustine, P. Barker, F. Pahmeyer, G. E. Ryder, F. E. Woodman, S. B. Flagg, C. H. McClure.

In all steaming tests made on the hand-fired furnace the stoking was done by the same fireman, Henry Arrens, who always did his work faithfully and proved to be exceptionally skillful.

DESCRIPTION OF STEAM PLANT AND APPLIANCES USED IN STEAMING TESTS.

STEAM PLANT AT ST. LOUIS, MO.

The steam plant at St. Louis, Mo., was installed in a building having a floor area of 94 by 54 feet. The building was a temporary, inexpensive, wooden-frame structure covered with sheet-steel siding and a composition roof.

The boiler room which occupied a floor area of 54 by 43 feet was equipped with two Heine water-tube boilers of 210 horsepower each, and one Frost horizontal multitubular boiler of 100 horsepower. Each boiler had a separate steel stack and independent brick setting. Ordinarily the two Heine boilers were fed with separate injectors, but a steam feed pump was so connected that it could be used for supplying any boiler if occasion demanded. Only the Heine boilers were used for the tests, the horizontal multitubular boiler furnishing steam to the coal washery and to several exhibits on the exposition grounds. Soon after the close of the exposition this boiler was removed from the boiler room.

When the fuel-testing plant was first set in operation the other equipment besides that already mentioned consisted mainly of the following apparatus and instruments:

Two platform scales and a charging car for weighing coal.

Two platform scales and two weighing tanks for weighing water.

Two suction tanks from which the measured water was fed by the injectors into the Heine boilers.

Two flue-gas samplers as prescribed by the code of the American Society of Mechanical Engineers for conducting boiler trials.

Special flue-gas samplers designed and built at the plant.

One Orsat apparatus for analyzing flue gases.

Two flue-gas thermometers.

One thermocouple for measuring furnace temperatures.

One set of thermometers for measuring outside, boiler-room and feed-water temperatures.

One separating and one throttling calorimeter for determining the moisture in steam.

Four draft gages for taking draft measurements.

When the testing work was resumed early in 1905 the following instruments were added to the equipment:

One recording flue-gas thermometer.

Two recording draft gages.

One Wanner optical pyrometer for measuring furnace temperature.

A Sturtevant blower direct-connected to a steam engine was installed in such a way that forced draft could be used with either of the two Heine boilers, only one of which was under steam at a time.

The steam generated was used in an Allis-Chalmers Corliss engine, 22 by 42 inches in size, running noncondensing, and driving a 200-kilowatt Bullock generator. The current was distributed at the switchboard to electric motors in various parts of the fuel-testing plant, or was used to operate a miniature railroad in one of the exhibits. During about the first 40 tests current not thus consumed was absorbed by a water rheostat which was used to regulate the load of the engine, and consequently the amount of steam taken out of the boiler. However, this method of regulating the steam consumption was not quite satisfactory; therefore a 3-inch blow-off pipe was connected to the steam main and provided with a throttling valve which

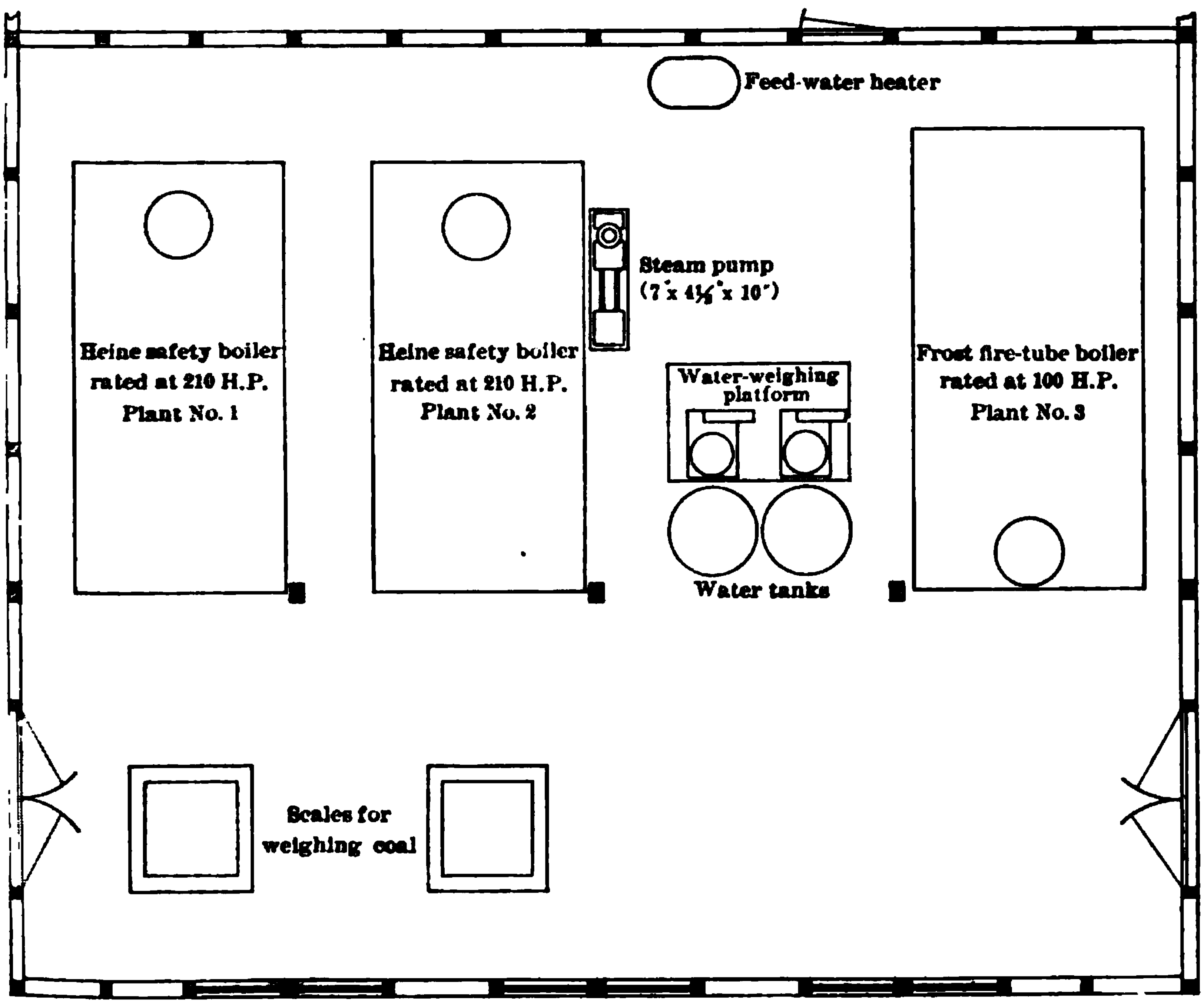


FIGURE 1.—Plan of steam plant showing location of boilers and equipment.

was used to regulate the flow of steam from the boiler directly into the atmosphere. By means of two sprocket wheels and a chain the regulating valve could be manipulated from in front of the boiler by the man managing the fire. This method of steam regulation was very satisfactory and was used for all subsequent tests made at St. Louis and at Norfolk.

GENERAL ARRANGEMENT OF TESTING APPLIANCES IN THE BOILER ROOM.

The general arrangement of the apparatus used in the boiler room during the steaming tests at the St. Louis Exposition is shown in figure 1. The water-weighing scales and the tanks were placed on a

wooden platform about 4 feet high so that the weighed water could be run by gravity into the suction tanks standing on the boiler-room floor. The Orsat apparatus was placed in the rear of the boilers where the gas analyses were made. There were no storage bins for the coal to be tested. As a rule, only one kind of coal was placed on the boiler-room floor each morning before a steaming test was started.

Before the steam tests were resumed in 1905 some improvements were added to the plant which greatly facilitated the testing work. The plan of this improved boiler room is shown in figure 2. Four bins having chutes opening into the boiler room were built on the out-

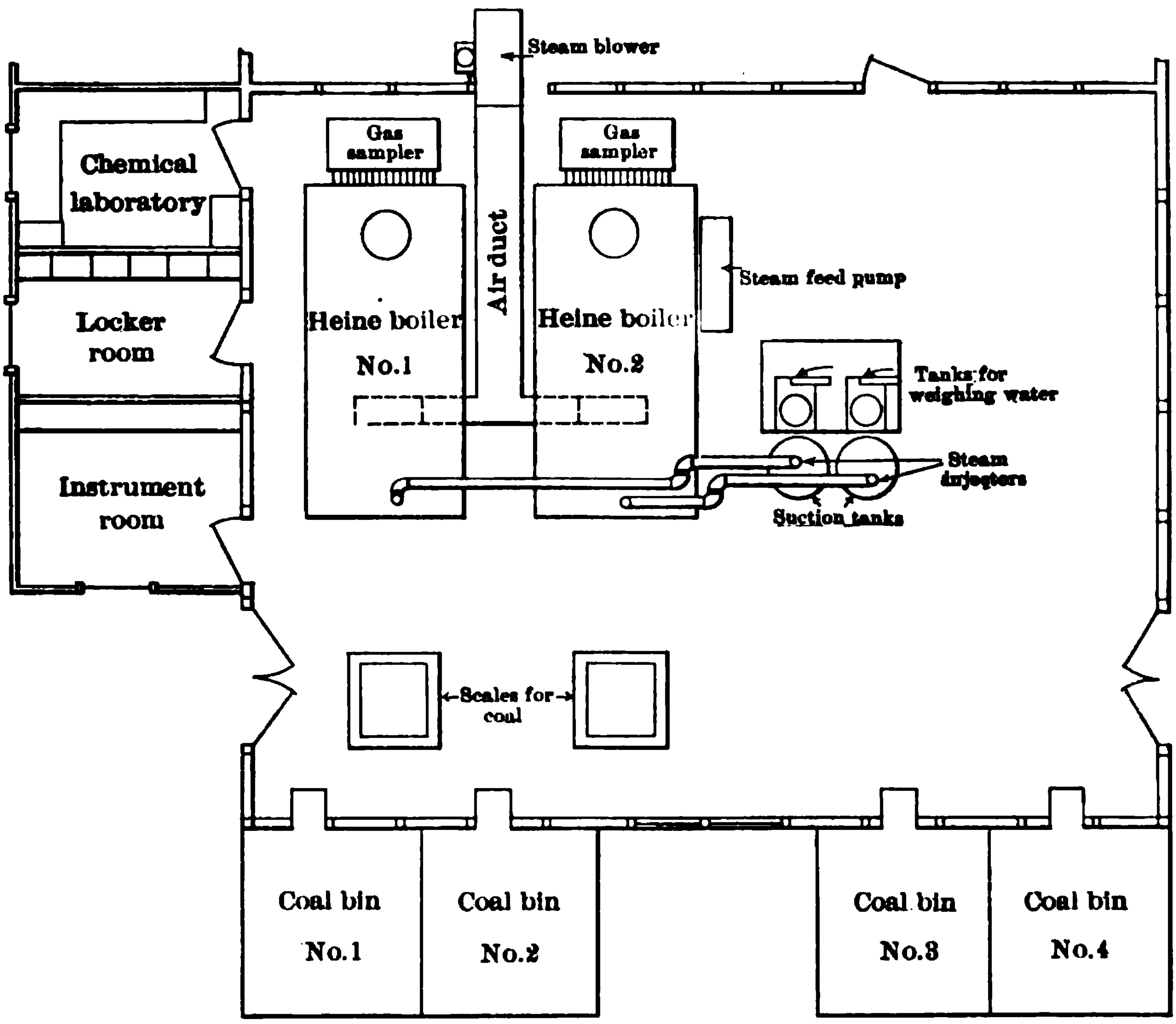


FIGURE 2.—Plan of improved steam plant at St. Louis, Mo.

side of the front wall. The bottoms of the bins were inclined and sufficiently elevated for the coal to run by gravity into a charging car placed under the chutes. Each bin had a capacity of about 25 tons of coal, a quantity that was sufficient for four or five tests. Thus it was possible to store four different coals in the bins and arrange the sequence of the tests in more logical order than was before possible. Besides, the absence of coal on the firing floor made the boiler room cleaner, a feature that encouraged more accurate work on the part of the observers. To promote further the accuracy and the reliability of the work three small rooms were built on the

left side of the boiler room, as shown in figure 2. The rear room had a floor space of 12 by 14 feet and was equipped as a chemical laboratory for making furnace-gas and flue-gas analyses. The front room was used as an instrument room. In it were mounted the recording draft gages and the recording flue-gas thermometer. Shelves were also provided for reserve instruments, for tools, and for keeping log-sheet blanks. The middle room was used as a wash and locker room.

A suitable platform with a stairway leading to it was built on top of each of the Heine boilers. The object was to make the upper portion of the boilers easily accessible for such observations as the determination of the moisture in the steam and the flue-gas temperature.

The Sturtevant steam blower was placed in the engine room, back of the boilers, and the underground air duct was run between the Heine boilers, discharging air into their ash pits as indicated in figure 2.

STEAM PLANT AT NORFOLK, VA.

The fuel-testing plant at Norfolk, Va., occupied about one-half of the Power and Alcohol Building at the Jamestown Exposition. This building, like most of the others on the exposition ground, was a temporary structure. The fuel-testing plant comprised the steam-engineering, the gas-producer, the briquetting, the liquid-fuel and the research divisions, each of which was given sufficient floor space for its apparatus and for carrying on its work.

The steam plant occupied a floor space of about 54 by 54 feet. The equipment consisted of two Heine boilers which were moved from the St. Louis plant, and one Babcock & Wilcox boiler of the semi-marine type. One of the Heine boilers was set up with a Jones underfeed stoker and the other with a hand-fired furnace and plain grate. The Babcock & Wilcox boiler was set up with a Roney stoker. All three boilers were supplied with mechanical draft, each having a separate exhaust fan. Besides these fans the Sturtevant pressure blower used in the St. Louis plant was so installed that it could discharge air into the ash pits of the hand-fired Heine boiler and the Babcock & Wilcox boiler. The Jones underfeed stoker was served with an independent pressure blower and a coal-feed regulator. Pipe connections were made in such a way that either injectors or a steam pump could be used for feeding the boilers. During a test the injector always supplied the feed water. The connections were such that it was certain that all the water weighed was fed into the boiler and that unweighed water could not get in.

All the other special apparatus and instruments used in the steaming tests at the St. Louis plant, excepting the flue-gas samplers, were moved to the Norfolk plant and used there. The flue-gas samplers were of special improved design and were constructed at the plant; they will be described in detail later on.

GENERAL ARRANGEMENT OF TESTING APPLIANCES IN THE BOILER ROOM.

Figure 3 shows the general arrangement of the testing apparatus in the boiler room at the Norfolk plant. The three exhaust fans were placed in the rear of the boilers upon a firm wooden platform which was somewhat higher than the top of the highest boiler setting. A stairway leading to this platform made the fans easily accessible. Special platforms with stairways were also provided on top of each boiler, which facilitated taking the calorimeter readings and other observations on top of the boilers. The water-weighing apparatus

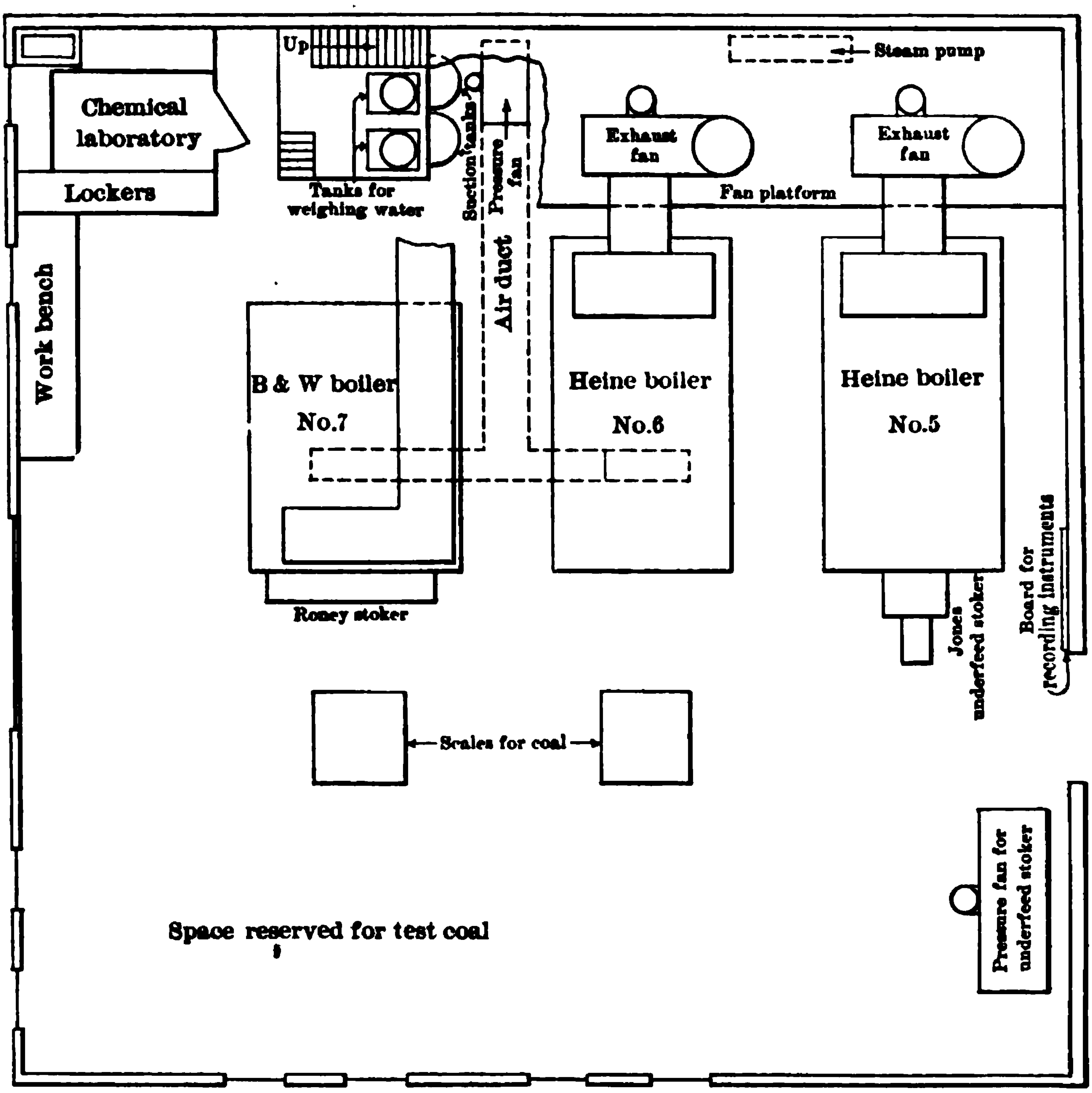


FIGURE 3.—Plan of steam plant at Norfolk, Va.

was placed on platform similar to that used at St. Louis. A dust-proof room 14 by 16 feet was built in the corner of the boiler room and equipped as a chemical laboratory for analyzing flue gases. The same room was used for storing reserve instruments and log-sheet blanks. The instruments were mounted on a board on a wall near the front of boiler No. 5. There were no storage coal bins, the coal for a test being piled on the floor back of the scales, from which place it was shoveled by hand into the charging car.

GENERAL CONDITIONS OF TESTS.

The steam generated in the boilers was used in a De Laval steam turbine, which was connected by means of the usual high-speed gear to an electric generator of the same make. The current from the generator was used by the various motors around the testing plant. When a steaming test was run the steam pressure in the boiler was regulated by a special blow-off pipe which exhausted the steam from the boiler directly into the atmosphere.

BOILERS.

The same two Heine boilers were used for all tests reported in this bulletin. However, at various times considerable changes were made

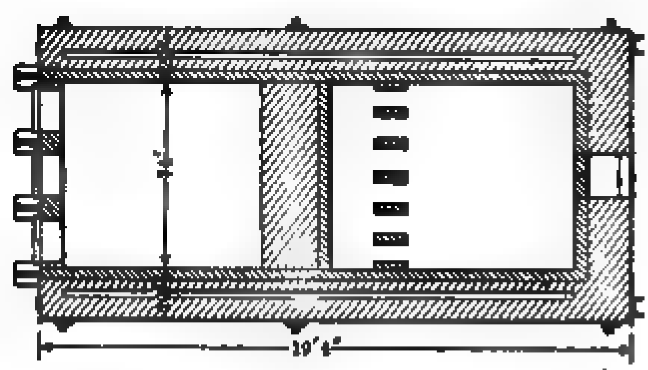


FIGURE 4.—Dimensions and details of setting of boilers Nos. 1 and 2.

in their settings. Because of these changes it was necessary to make distinctions and to designate the boilers by different numbers after each radical change.

The two boilers as they were originally set up at St. Louis were designated as No. 1 and No. 2. The Frost boiler was called boiler No. 3 The arrangement of these boilers is shown in figure 1. When testing work was resumed in 1905 the plain grate of boiler No. 2 was replaced by a McClave rocking grate of approximately the same area; but as the other essentials of the setting remained the same, the boiler retained its designation of No. 2.

In September, 1906, boiler No. 1 was entirely reset with a specially designed air-tight setting; it was then designated as No. 4. When the fuel-testing plant was moved to Norfolk, Va., one of the boilers was set up with a Jones underfeed stoker and was designated as No. 5. The other boiler was erected with a standard plain-grate setting, with the exception that a special horizontal baffle was inserted among the tubes. This boiler was designated as No. 6. The additional Babcock & Wilcox boiler in the Norfolk steam plant was set up with a Roney stoker and was designated as No. 7. Figure 3 illustrates the arrangement of the boilers.

BOILER NO. 1.

The dimensions and the details of the setting of boiler No. 1 are shown in figure 4. The construction of the boiler proper is shown in detail in figure 5. Table 1 gives the principal dimensions of the boiler and settings.

TABLE 1.—*Principal dimensions of boiler No. 1.*

Commercial name	Heine safety boiler
Type	Horizontal water-tube
Capacity as rated by builders ... horsepower..	210
Boiler:	
Length of steam drum ... feet..	21$\frac{1}{12}$
Inside diameter of drum ... inches..	42
Number of tubes	116
Internal diameter of tubes ... inches..	3.26
External diameter of tubes ... do....	3.50
Length of tubes exposed ... feet..	17$\frac{1}{12}$
Water-heating surface of tubes ... square feet..	1,897
Water-heating surface of water legs ... do....	91
Water-heating surface of steam drum ... do....	43
Total water-heating surface ... do....	2,031
Total water space ... cubic feet..	287
Steam space ... do....	73
Furnace:	
Kind of grate	Plain.
Length of grate ... feet..	6.58
Width of grate ... do....	6.16
Dimensions of air spaces ... inches..	0.5 by 17.5
Area of grate ... square feet..	40.55
Ratio of grate area to air spaces	40 to 17
Mean height of furnace above grate ... inches..	26
Total combustion space, including combustion chamber ... cubic feet..	250
Ratio of combustion space to grate area	6.2
Cross-sectional area between tubes ... square inches..	1,612
Area of gas entrance to tube chamber ... do....	1,070
Area of gas exit from tube chamber ... do....	640
Depth of ash pit below grate surface ... inches..	25
Stack:	
Construction	Steel, supported by guy wires.
Height of top above grate ... feet..	113.25
Diameter ... inches..	37.5
Area of stack ... square inches..	1,104

When there was 3 inches of water in the water glass the boiler contained 16,800 pounds of water at 70° F. Each additional inch of water, as shown by the water glass, was equal to 340 pounds.

These figures were determined by calibrating the boiler with cold water at 70° F. and noting the height of water in the gauge glass as the water was drawn from the blow-off and weighed.

Setting.—The details of the setting are shown in figure 4. The side walls were 20 inches thick up to the top row of tubes and contained a 2-inch air space; above that they were 13 inches thick, and solid. On the inside of the furnace the 20-inch walls were protected by a fire-brick lining about 5 inches thick. The boiler tubes in the lowest row were inclosed with C-shaped tiles for their entire length, except 30 inches in the rear of the boiler where an opening was

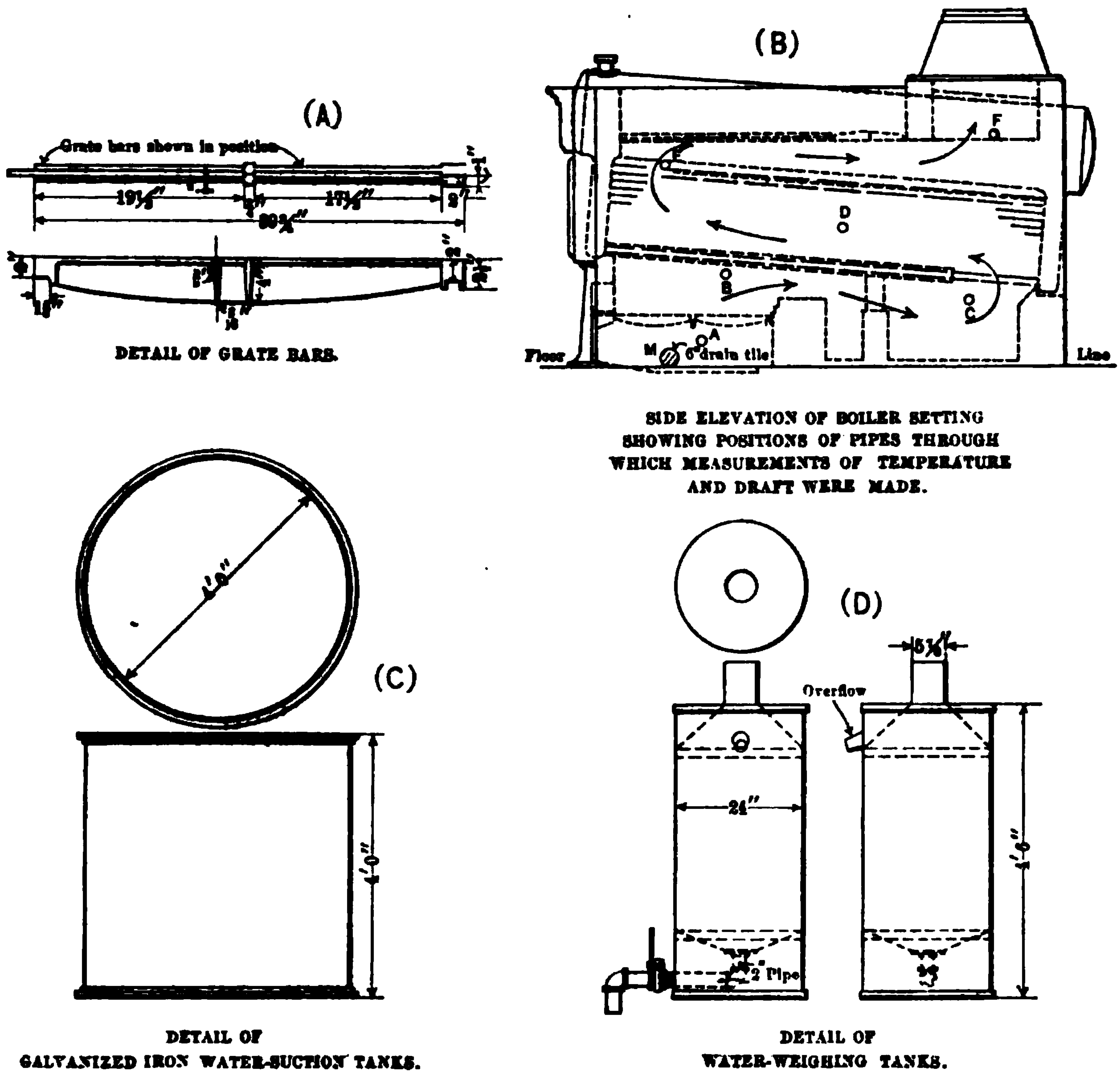


FIGURE 5.—Details of plain grate bars, gas path through boiler, suction tanks, and water-weighing tanks.

left to admit the gases into the tube chamber. A similar opening was left in the baffle on the top row of tubes in the front of the boiler to allow the gases to leave the tube chamber and flow under the steam drum into the stack; this opening was only 18 inches long. Thus the gases traveled the usual path of the Heine boiler as shown in figure 5, B. The furnace was entirely lined with refractory material, which made it possible to develop and maintain high temperatures, and, as it was thought, to insure perfect smokeless combustion. The bridge wall in front was built to within 11 inches of the tile roof.

Several 2-inch pipes 24 inches long, provided with caps on their outer ends, were bricked into the side walls in order that observations of gas pressures and temperatures at the important places inside the setting could be made. Through these openings special gas samples were also collected. The location of these pipe peepholes is shown by the letters A, B, C, D, E, and F in figure 5, B.

Gas-mixing arch.—A special fire-brick structure was built in the combustion chamber about 18 inches from the back of the bridge wall. The object of this arch was to mix the volatile combustible matter with the air and thus facilitate combustion. This arch soon melted down and was rebuilt several times with the best fire brick obtainable, but it never lasted long enough to have much commercial significance. A detailed discussion of this arch is given in Part II of this bulletin, page 296.

Hughes smoke preventer.—The boiler was equipped with a Hughes automatic smoke preventer, a device that after each firing automatically admitted air above the fuel bed and at the same time opened steam jets to mix the air with the combustible matter driven off the freshly fired coal. Both the air and the steam jets were cut off slowly by a weighted piston working in a cylinder filled with oil. The slow motion of the piston was obtained by passing the oil through a small pipe containing a valve; by regulating this valve the time during which the steam jets and the air dampers remained open could be adjusted as desired. The steam jets were not used, but the damper doors for admission of air were operated on most of the tests in accordance with the judgment of the man in charge of the fire. The same effect might have been obtained by leaving the fire doors slightly open for about two minutes after each firing.

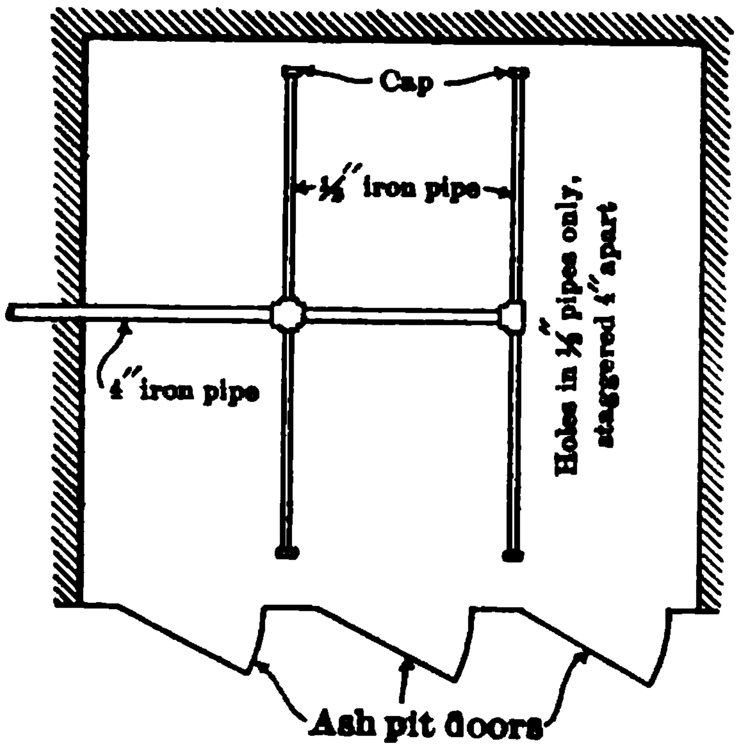


FIGURE 6.—Arrangement of steam piping under grates of boilers Nos. 1, 2, and 4.

Grate.—The grate consisted of single bars illustrated in figure 5, A. They were one-half inch wide and constructed to give an air space of one-half inch

Steam in the ash pit.—During the first few tests much trouble was experienced from clinker sticking to the grate bars. It was decided, therefore, to put a system of piping in the ash pit and admit steam under the grate. This pipe arrangement is shown in figure 6. The use of steam in the ash pit was preferred to water inasmuch as it was desired to keep the ash dry. Live steam was used because the piping was much simpler than if exhaust steam were to be used.

A. STEAM PIPING AND CALORIMETER CONNECTIONS TO STEAM MAIN

B. EAMES DIFFERENTIAL DRAFT GAGES AND ORSAT APPARATUS.

The steam thus used was not, however, charged to the coal under test in any case. This use of steam under the grate reduced the difficulty arising from clinker.

Stack.—The stack was made of steel and rested on a suitable hood placed over the rear wall of the boiler, which provided a direct gas passage into the stack. The stack was 37.5 inches in diameter and 113.25 feet high above the grate. A damper was placed in the cylindrical portion immediately above the hood. Wires were run from the damper over suitable pulleys to the front wall of the boiler room, where they were within easy reach of the man in charge of the fire.

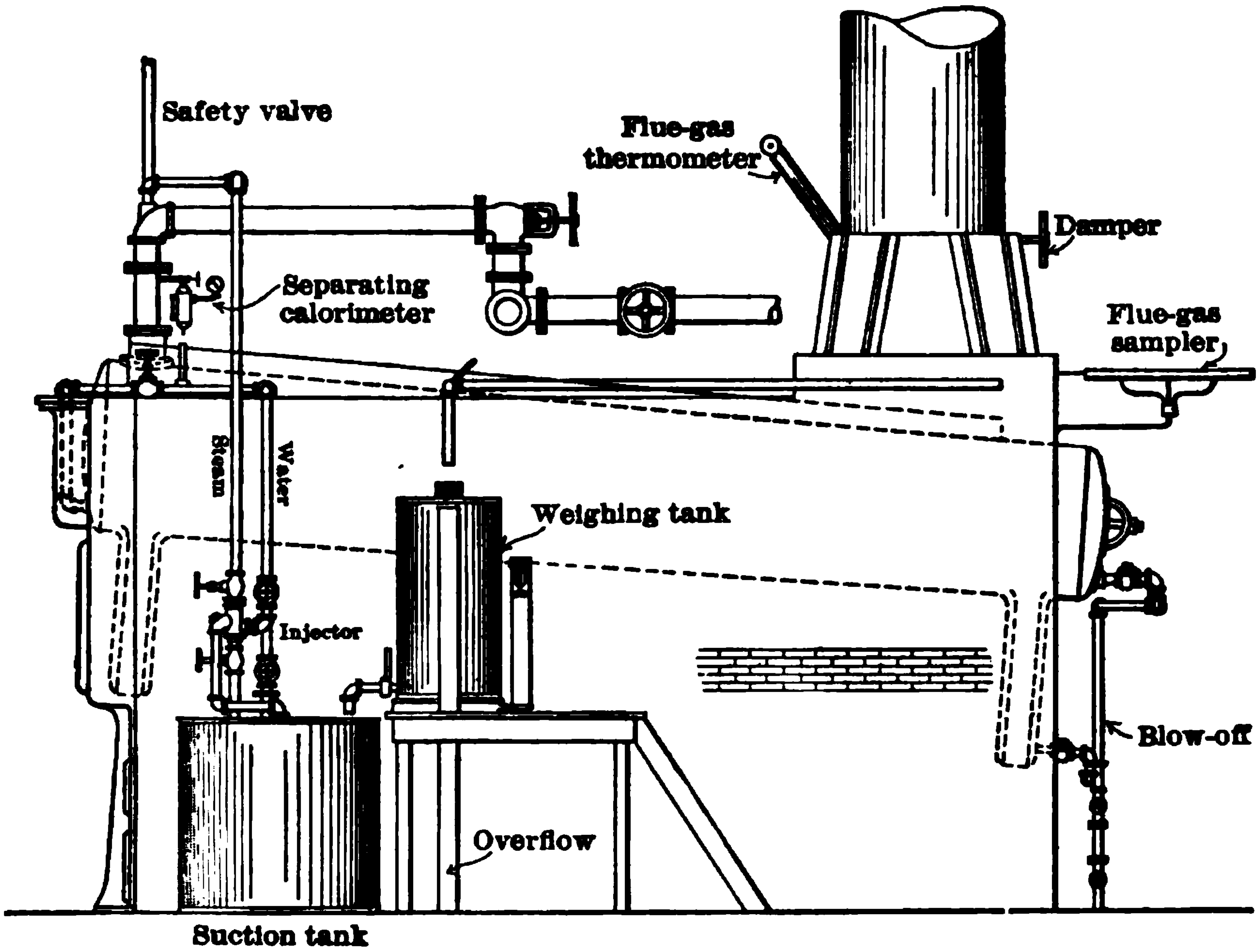


FIGURE 7.—Side view of setting of boiler No. 1, showing arrangement of piping, tanks, etc.

Steam pipes.—The steam pipes from the boiler to the header are illustrated in figures 7 and 8 and Plate 1, *A*. Steam was taken from the boiler through a tee and a short section of 6-inch pipe in which was placed a calorimeter nipple. A safety valve was connected to the outlet of the tee. All steam pipes and the feed and water pipe from the injector were covered with good sectional pipe covering. The steam pipe leading to the Corliss engine contained a separator placed about 18 inches above the throttle valve.

BOILER NO. 2.

Boiler No. 2 was at first exactly like boiler No. 1 with respect to construction and setting, so that the description of boiler No. 1 applies to boiler No. 2. In 1905, soon after the testing work was

resumed, the plain grate of the boiler was replaced by a McClave rocking grate arranged in four sections of somewhat smaller area. This grate was 6.07 feet long by 6 feet wide, and had an area of 36.4 square feet. The air spaces in the grate occupied 30 per cent of the total area. Other details of the boiler setting remained the same, and therefore its designation was not changed.

BOILER NO. 3.

No official tests were made on boiler No. 3, and therefore its description need not be given here.

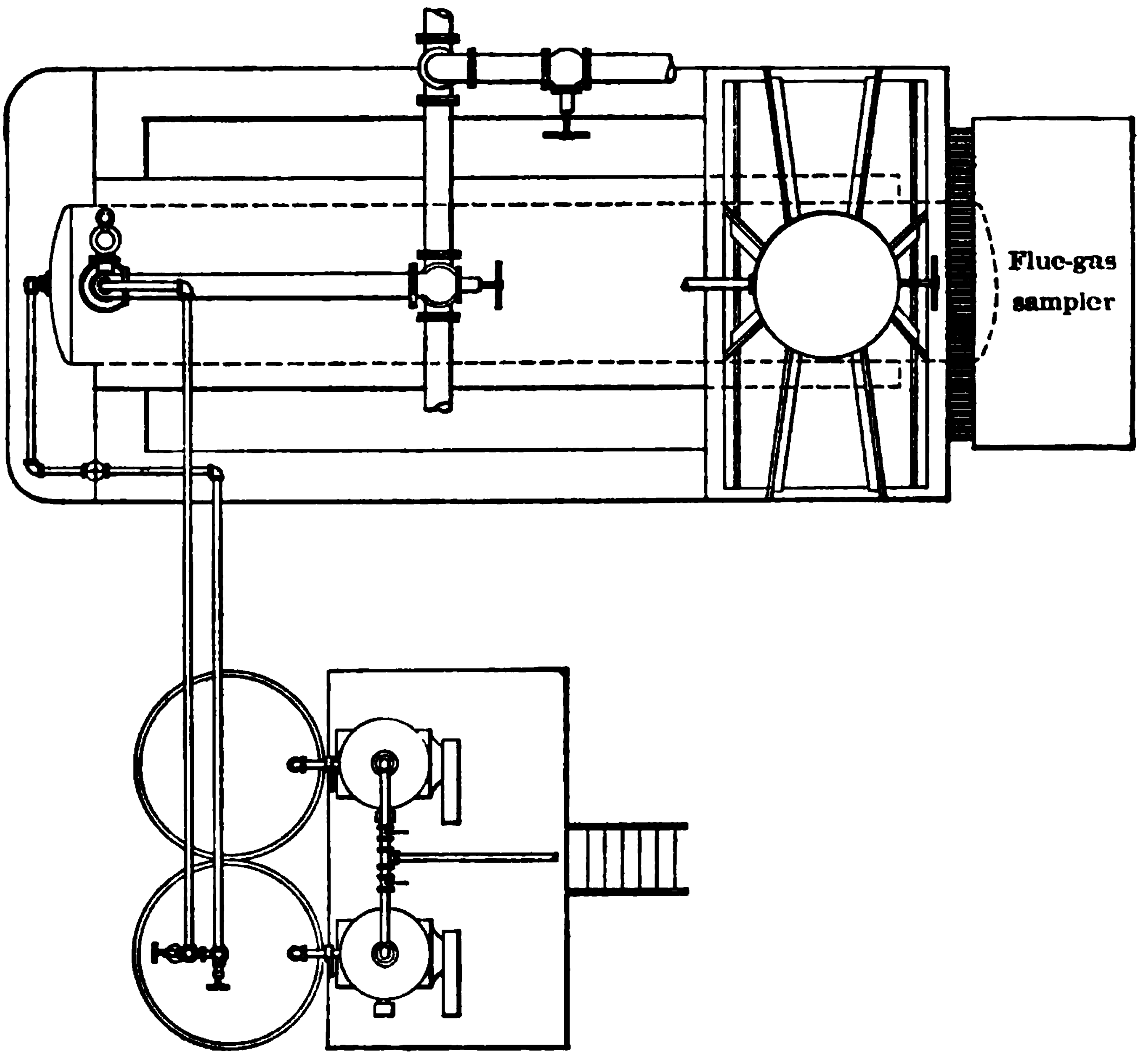
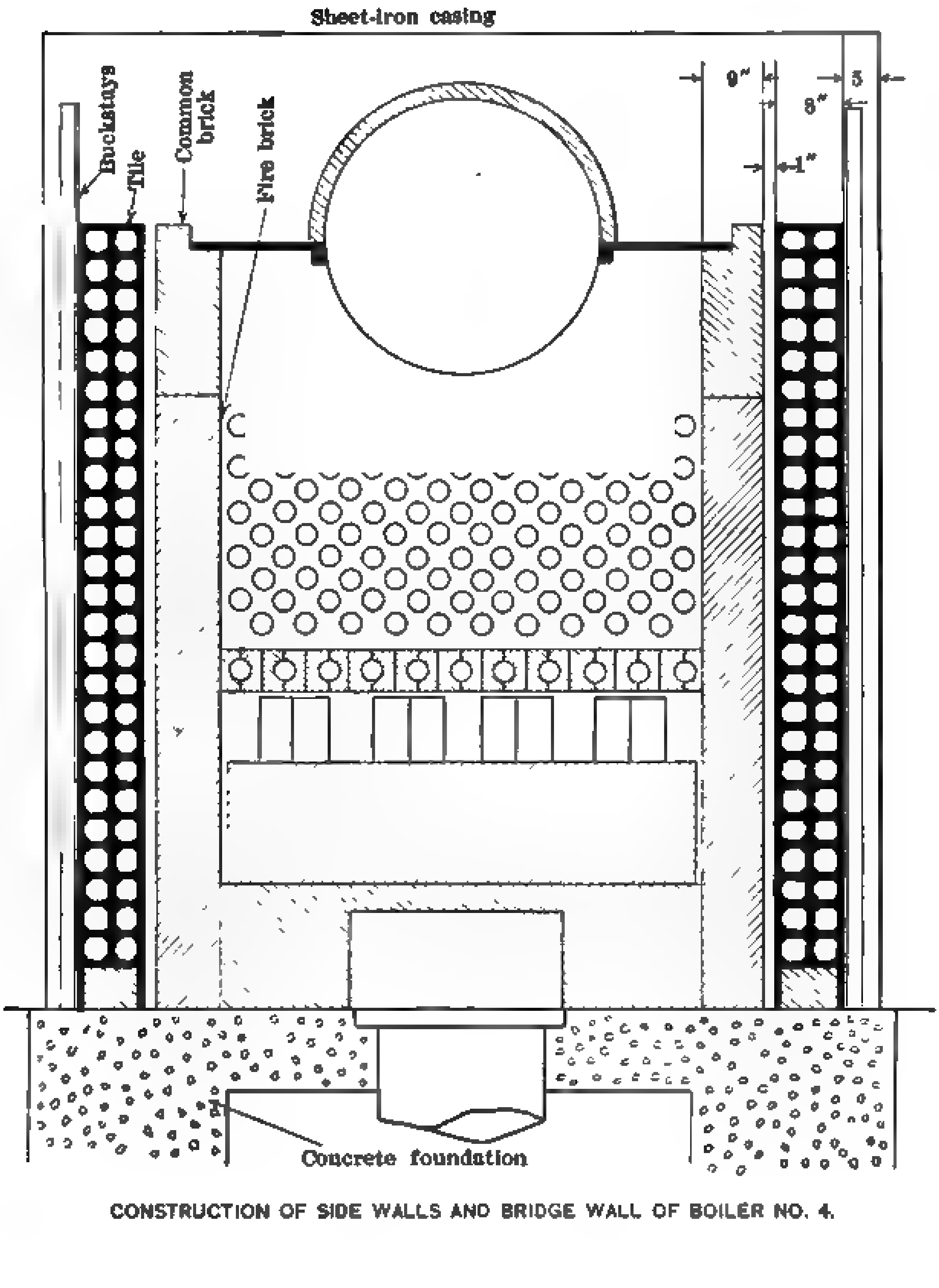


FIGURE 8.—Top view of piping, tanks, etc., boiler No. 1.

BOILER NO. 4.

Boiler No. 4 was boiler No. 1 reset in a specially designed air-tight setting. The setting as described under boiler No. 1 and illustrated in figure 4 was in use from August, 1904, to August, 1906. During this time it was believed that a considerable quantity of air filtered into the setting through the brick wall, although a man was almost constantly employed in stopping and painting over any visible cracks.

It was further believed that if these leaks were absolutely prevented the over-all efficiency would be raised, and more accurate analyses of the flue gases could be made on which to base reliable heat balances.



CONSTRUCTION OF SIDE WALLS AND BRIDGE WALL OF BOILER NO. 4.

It was desired particularly to obtain accurate heat balances. Accordingly, in August, 1906, a specially designed boiler setting was built and entirely inclosed in an air-tight sheet-iron casing. The latter was made of No. 16 sheet iron and bolted together with ¼-inch machine bolts, the lap joints being made air tight by putting tar roofing paper between the metal plates. The whole structure of the casing was kept in shape and in place by stiffeners of 2-inch angle iron.

The side wall of the setting consisted of two entirely independent walls, separated by a 1-inch air space. The inner wall was 9 inches thick and was built entirely of fire brick. The outer wall was 8 inches thick and was built of special hollow tiles. These tiles were 10 inches long, 8 inches wide, and 4 inches high, and had two air spaces each 3½ inches square, running lengthwise. Figure 8 shows the construction of the side walls.

The sheet-iron casing was placed 5 inches from the outside of the hollow tile wall so that there were four air spaces between the inner wall and the sheet-iron casing. The top of the casing was about 4 inches higher than the highest point of the steam drum. In the rear the top was fitted under the sheet-iron hood of the stack. In the front and in the rear access to the boiler was had by suitable doors in the casing, which were kept air tight by rubber gaskets.

Furnace.—While this special setting was being erected some changes were introduced in the construction of the furnace. The grate was lowered 4 inches, with the object of obtaining more space between the grate and the roof of the furnace, so that a thicker fuel bed could be used when burning briquets. To enable the fireman to control the top of the fuel bed, the front of the furnace was made with double firing doors one above the other. It was the intention to use the upper doors with thick fuel beds, and the lower doors with thin fuel beds. The combustion-chamber mixing arch as previously used was abandoned; instead of it eight piers of small fire brick were built on top of the bridge wall, as shown in figure 8. These piers had several advantages over the mixing wall. They were easier to build, cost less, and lasted longer. It would seem that another advantage of these piers was that the mixing of the gases was done closer to the grate, giving the mixture more space in which to burn and more time for complete combustion. However, this was not so, because after the mixture left the piers, it passed in a straight line into the openings among the tubes of the boiler. The mixing wall in the combustion chamber diverted the gases from a straight line, making their path longer and thus making more of the combustion space effective.

Five openings into the furnace were provided on each side of the setting for the purpose of measuring temperatures and sampling gases. These openings were made by bricking into the walls pieces of iron pipe about 30 inches long with two threaded flanges and a cap on the

outside end. An air-tight joint with the casing around each pipe was obtained by means of the two flanges. When any of these openings were not in use they were kept closed by the threaded caps.

The dimensions and other features of this special setting were the same as in the setting of boiler No. 1.

BOILER NO. 5.

Boiler No. 2 of the St. Louis plant was set up at Norfolk with a Jones underfeed stoker and designated as boiler No. 5. Figure 9 illustrates the boiler and its setting.

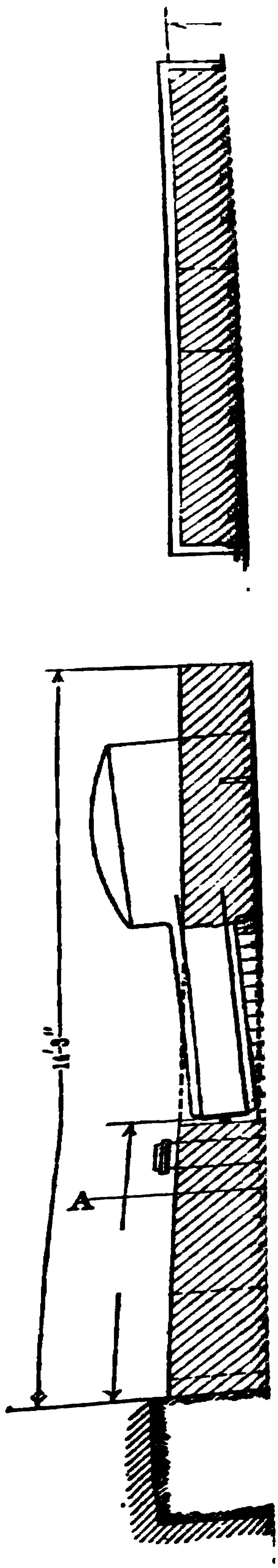
Stoker.—The underfeed stoker is a device that feeds fresh coal into a horizontal retort underneath the fuel that has already ignited. The retort is in the middle of the furnace and extends from the front furnace wall nearly to the bridge wall. The fuel burns in a heap and the refuse, which is generally melted, slides to the sides of the furnace and must bé pulled out with a hook through the doors provided for this purpose in the front of the furnace. The air necessary for the combustion of the coal is admitted under pressure through numerous small openings at the top of the sides of the retort. The method of introducing the air is not unlike that used in the blacksmith forge, the air entering the retort in two opposite rows of jets. The coal is pushed beneath the burning heap of fuel in comparatively large charges by a plunger operated by a steam-actuated piston in a cylinder similar to that of a steam engine. This feeding mechanism is controlled by an automatic device. On each side of the retort is a dead plate with no perforations; all the air is added either through the tuyeres or the cleaning doors.

Setting.—The details of the setting are illustrated in figure 9. The boiler was set 2½ feet higher than it was when equipped with the hand-fired furnace. The walls were built and the baffles inserted exactly in the same way as described in connection with boiler No. 1.

Gas-mixing arch.—There was no gas-mixing structure in the combustion chamber of this boiler.

Draft.—The pressure drops ("draft") were produced by fans. An exhaust fan was placed between the hood and the stack, which exhausted gases from the setting. The reduction in pressure in the hood could be regulated by controlling the speed of the fan; this was done by adjusting the governor of the engine driving the fan. The pressure could be further regulated by means of a damper placed in the flue between the fan and the hood.

The Jones underfeed stoker made necessary the use of a pressure fan also. This fan was direct-connected to a 5 by 5 inch steam engine. The speed of the fan and consequently the pressure of air entering the tuyeres was regulated by an automatic device which also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controlled the fuel supply so that the man running the fire was left free to operate the damper.

Steam pipe.—The steam pipe between the boiler and the header was similar to that illustrated in figure 7, with the exception that the vertical section of the pipe containing the calorimeter nipple was 4 feet long. All steam pipes and the feed-water pipe from the injector were covered with sectional pipe covering.

TABLE 2.—*Principal dimensions of boiler No. 5.*

Commercial name		Heine safety boiler.
Capacity as rated by builders, horsepower		210
Boiler:		
Dimensions same as given for boiler No. 1 in Table 1, page 18.		
Furnace:		
Kind of stoker		Jones underfeed.
Length of furnace from front furnace wall to bridge wall	feet	6.3
Width of furnace between side walls	do	6.2
Length of retort	do	5
Width of retort	do	1.125
Area of retort	square feet	6.625
Dimensions of air openings	inches	0.5 by 2.25
Total area of air openings	square inches	72.25
Average height of furnace	inches	45
Total combustion space including combustion chamber	cubic feet	425
Cross-sectional area between tubes	square inches	1,612
Area of gas entrance to tube chamber	do	1,070
Area of gas exit from tube chamber	do	640
Pressure fan:		
Driven by a 5 by 5 inch steam engine direct-connected to shaft of fan.		
Maker of fan		American Blower Co
Diameter of casing	feet	9
Width of casing	inches	24
Diameter of wheel	feet	8.3
Approximate number of revolutions when boiler ran at rated capacity		400
Exhaust fan:		
Driven by a 5 by 5 inch steam engine direct-connected to fan.		
Diameter of casing	feet	7
Width of casing	inches	36
Diameter of wheel	feet	5.5
Diameter of gas inlet	inches	42
Diameter of gas outlet	do	36
Approximate number of revolutions when boiler ran at rated capacity		400
Length of flue from boiler to fan	feet	10
Diameter of flue	inches	42
Stack:		
Construction		Steel supported by guy wires.
Height above grate	feet	60
Height above center of exhaust fan	do	40
Diameter	inches	36
Area of cross section	square inches	1,018

BOILER NO. 6.

Boiler No. 4 of the St. Louis plant when moved to Norfolk was set up with a hand-fired furnace and designated as boiler No. 6. The walls were built of the same material as they were at the St. Louis plant and the setting was inclosed in the same sheet-iron casing. The grate was raised to the same height that it had in the standard setting of boilers Nos. 1 and 2, and the standard cast-iron furnace front having three single firing doors was used in place of the one of

special design. The furnace had the usual tile roof made of flat-bottomed tube tiles. The setting of boiler No. 6 is illustrated in figure 10.

Baffling.—The special feature of this setting was the double path for the gases through the tube space of the boiler. This double path

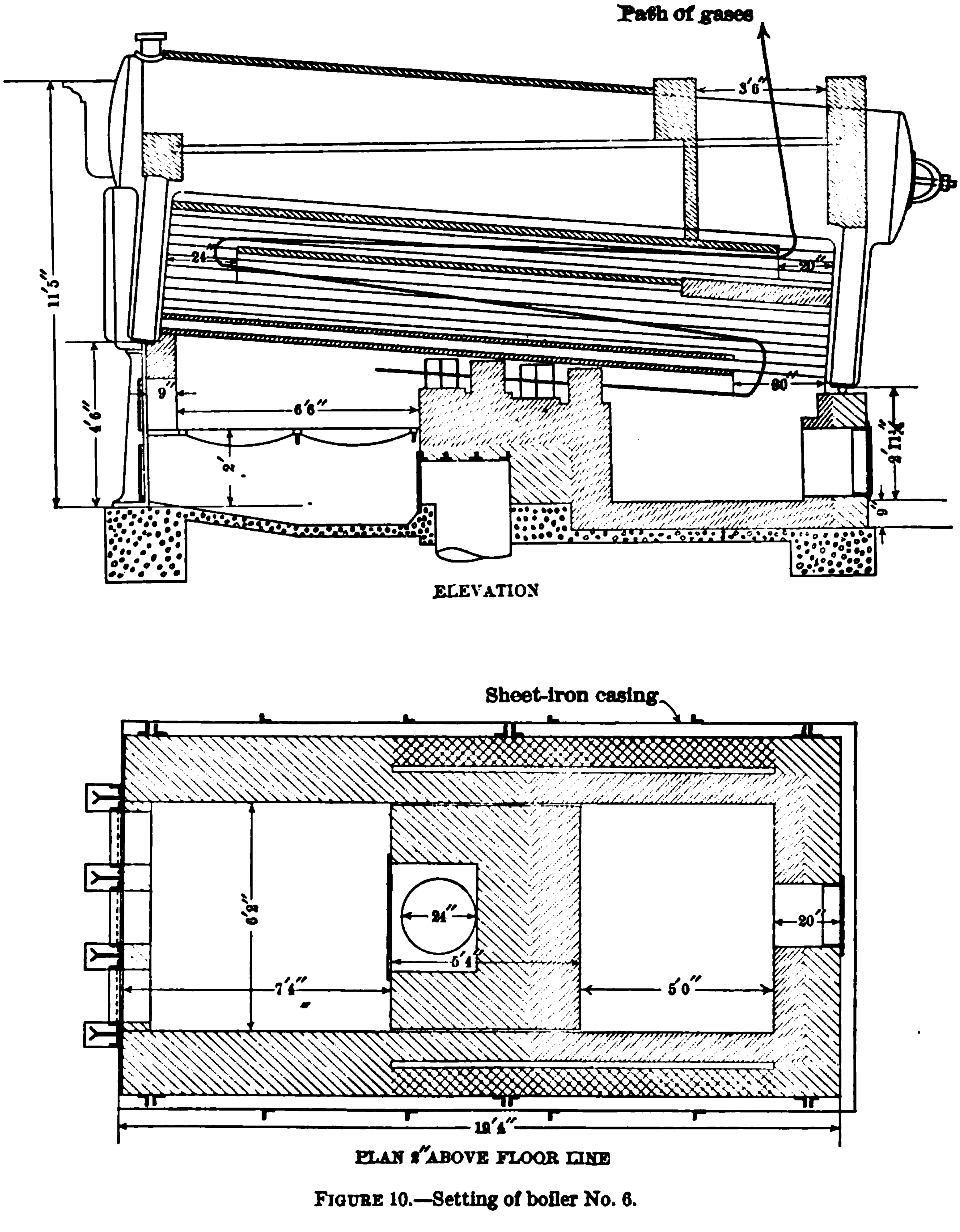

FIGURE 10.—Setting of boiler No. 6.

was obtained by inserting an additional horizontal baffle between the seventh and eighth horizontal row of tubes. This baffle divided the tube space into two unequal portions or chambers. The baffle and the path of the gases are illustrated in figure 10. The gases entered the tube space in the rear of the boiler and flowed under the inserted

baffle to the front of the boiler, coming in contact only with the lower six rows of tubes, not counting the one which supported the tile roof. At the front of the boiler the gases entered the upper portion of the tube space and flowed to the rear of the boiler, where they passed into the hood and out into the stack, not coming in contact with the steam drum, except a small part of it in the rear of the boiler. This method of baffling puts the heating surface of the tubes in the two passes in series, which arrangement causes a greater heat abstraction from the gases. This advantage is discussed more fully in Part II of this bulletin under the caption "Principles involved in heat transmission in steam boilers." To insert this additional baffle, the eighth horizontal row of tubes was taken out and the tiles forming the middle baffle were placed on top of the seventh row through an opening in the side wall. This method of baffling Heine boilers was devised by W. L. Abbott and A. Bement of the Commonwealth Edison Co. of Chicago.

Gas-mixing piers.—There was no gas-mixing structure in the combustion chamber of this boiler setting. However, a number of piers of small fire brick similar to the piers used in the setting of boiler No. 4 were built on top of the bridge wall, which, perhaps, served the same purpose as well. The location and construction of these piers is illustrated in figure 10.

Draft.—The pressure drops ("draft") were produced by an exhaust fan placed between the hood and the stack. A pressure fan was also connected to the ash pit so that air under pressure could be supplied to the latter when desired. The engine driving the exhaust fan was equipped with a centrifugal governor that could be adjusted to obtain any desired speed within certain limits. Besides this regulation of the fan the gas pressures (drafts) could be controlled by a damper placed in the flue connecting the hood with the fan. When using the pressure fan, the air pressure in the ash pit was controlled partly by a throttle valve on the fan engine and partly by a damper controlling the admission of air into the ash pit.

Steam pipes.—The method of piping the steam into the header was the same as illustrated in figure 7. On this boiler the vertical section of the pipe containing the calorimeter nipple was 6½ feet long. All steam pipes and the feed-water pipe from the injector were covered with sectional pipe covering.

TABLE 3.—*Principal dimensions of boiler No. 6.*

Commercial name		Heine safety boiler.
Capacity as rated by builders	horsepower..	210
Boiler:		
Water-heating surface of tubes	square feet..	1,897
Water-heating surface of water legs	do....	91
Total effective water-heating surface	do....	1,988
Other dimensions same as for boiler No. 1.		

Furnace:		
Type		Hand fired.
Kind of grate		Plain.
Length of grate	feet..	6.5
Width of grate	do....	6.1
Area of grate	square feet..	39.7
Dimensions of air spaces	inches..	0.5 by 17.5
Ratio of grate area to air spaces		40 to 17
Mean height of furnace above grate	inches..	28
Total combustion space, including combustion chamber	cubic feet..	175
Ratio of combustion space to grate area		4.41
Cross-sectional area between tubes	square inches..	1,612
Area of gas entrance to first pass in the tube chamber	do....	1,070
Area of gas entrance from first pass into second pass	do....	856
Area of gas entrance from second pass into hood	do....	713
Depth of ash pit below grate	inches..	26
Fans:		
Exhaust fan driven by a 5 by 5 inch steam engine direct connected to fan.		
Maker of fan		The Green Fuel Economizer Co.
Diameter of casing	feet..	7
Width of casing	inches..	38
Diameter of gas inlet	do....	42
Diameter of gas outlet	do....	36
Approximate number of revolutions when boiler ran at rated capacity		400
Length of flue from boiler to fan	feet..	10
Diameter of flue	inches..	42
Pressure fan driven by 4 by 4 inch steam engine direct connected to fan.		
Maker of fan		B. F. Sturtevant Co.
Diameter of casing	feet..	4.5
Width of casing	inches..	22
Diameter of air inlet	do....	30
Diameter of air outlet	do....	22
Approximate number of revolutions when boiler ran at rated capacity		500
Length of air duct from fan to ash pit	feet..	25
Diameter of air duct	inches..	24
Stack:		
Same as for boiler No. 5.		

OTHER APPLIANCES USED IN STEAMING TESTS.

WEIGHING SCALES.

All four scales were furnished by Fairbanks, Morse & Co. The two scales for weighing water were of 1,000 pounds capacity. They were set on a platform 4 feet high. The scales were calibrated with a 50-pound standard weight and a tank of water and were found correct.

The two scales used for weighing coal were of 2,000 pounds capacity. They were set in front of the boilers with their platforms flush with the floor of the boiler room.

WATER-WEIGHING TANKS.

The water fed into the boilers was weighed in two tanks specially designed and constructed for the purpose. These tanks are illustrated in figure 5, D. They were made of galvanized iron. The special feature of these tanks was the funnel-shaped bottom and the inverted-funnel top. This shape of the top and bottom permitted

accurate filling and quick emptying. The outlets of these tanks were provided with quick-opening gate valves. The capacities of the two tanks were 634 and 633 pounds of water at about 60° F. Owing to the small necks of these tanks, any possible variation in the height of the water above the overflow was so small that it could not be detected with the scales.

SUCTION TANKS.

The measured water was discharged into two suction tanks placed on the floor, as illustrated in figure 7. Figure 5, C, illustrates the details of the suction tanks. They were made of galvanized iron and were stiffened at the bottom and at the top with 1-inch angle irons. These tanks were equipped with floats which indicated the height of water in the tanks at all times. A difference of 1 inch in the height of water in each tank was equal to 59 pounds of water.

CHARGING CAR.

The coal-charging car was built entirely of steel; the size of the box holding the coal was 54 by 30 by 13 inches. One side of this box was hinged and could be lowered to make charging more convenient. The capacity of this car was 700 pounds of soft coal.

SAMPLING CANS.

Four sample cans were provided for keeping samples of the coal and ash. They were 18 inches in diameter and 30 inches high. They were made of galvanized iron and provided with close-fitting covers.

FLUE-GAS SAMPLERS.

In sampling the flue gases it was important that the sample collected should represent the average composition of the stream of gas leaving the boiler setting. To obtain such a representative sample, all the boilers previously described were equipped with special devices.

Boilers Nos. 1 and 2 were provided with gas samplers recommended by the code of the American Society of Mechanical Engineers. These apparatus were constructed beforehand and installed while the two settings were being erected. Details of construction are given in figure 11.

The sampler consisted essentially of a thin box of galvanized sheet iron. The width and length of this box was the same as the inside dimensions of the brick smoke flue supporting the hood of the stack. From this box 85 pieces of standard ¼-inch pipe each 5 feet long led to the flue and were so placed as to give one opening for each 40

square inches of flue area. These pipes were all of the same length and the ends were cut square, to insure the same flow of gas through all of them. They were bricked into the rear wall of the flue about 7 inches below the top. The location of the sampler with respect to the setting is shown in figure 7. As these pipes had to be adjusted to the right place in the flue area before the last three courses of brick were laid, it was impractical to have the pipes soldered into the box, therefore the side of the box through which these pipes passed was provided with a lip forming a narrow trough. The pipes fitted snugly into the holes in the lip and the side of the box and an air-tight

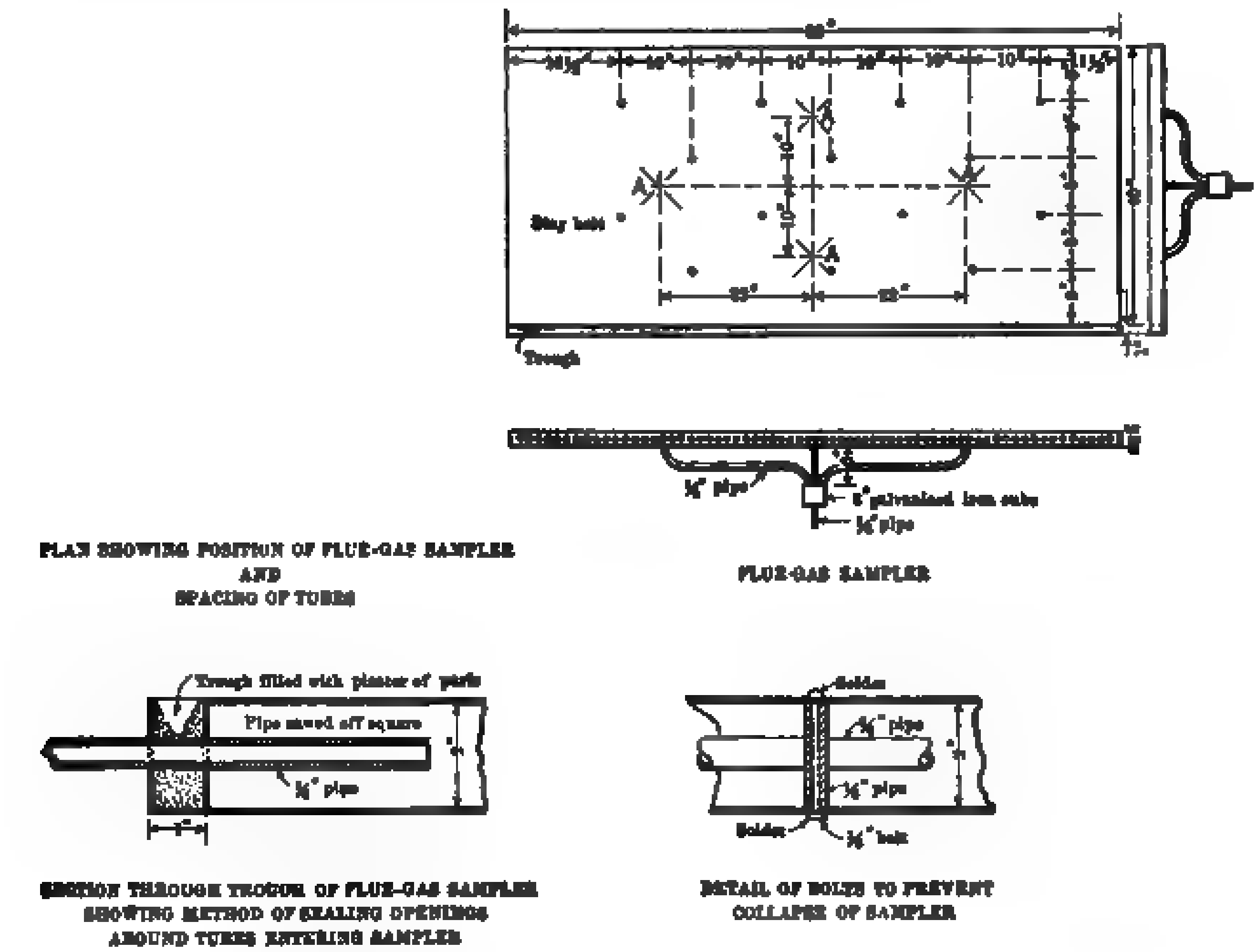

FIGURE 11.—Details of gas-sampling device used with boilers Nos. 1 and 2.

joint was obtained by filling the trough with plaster of Paris. As an additional precaution against leakage of air, a thin layer of pitch was spread over the plaster. The method of making this joint is illustrated in the lower left-hand corner of figure 11.

From the sample box four ¼-inch pipes led to a 3-inch cube of galvanized iron, and out of this cube the gas was drawn through a single ½-inch pipe connected to a water aspirator. The object of the four ¼-inch pipes and the cube was to draw gases from four different portions of the box and mix them in the cube before finally collecting them for chemical analysis. The aspirator caused a continuous flow of gases through the ½-inch pipe.

METHOD OF COLLECTING GAS SAMPLES.

The method of collecting samples of gas for chemical analyses is illustrated in figure 12.

A tee was fitted in the pipe leading from the cube to the aspirator and from the extra opening of this tee the gas sample was drawn through a filter into a collecting bottle. The "suction" was produced by first filling the collecting bottle A and the glass tube connecting it to the filter with water and then siphoning the water through a flexible rubber tubing into an empty collecting bottle B, placed on

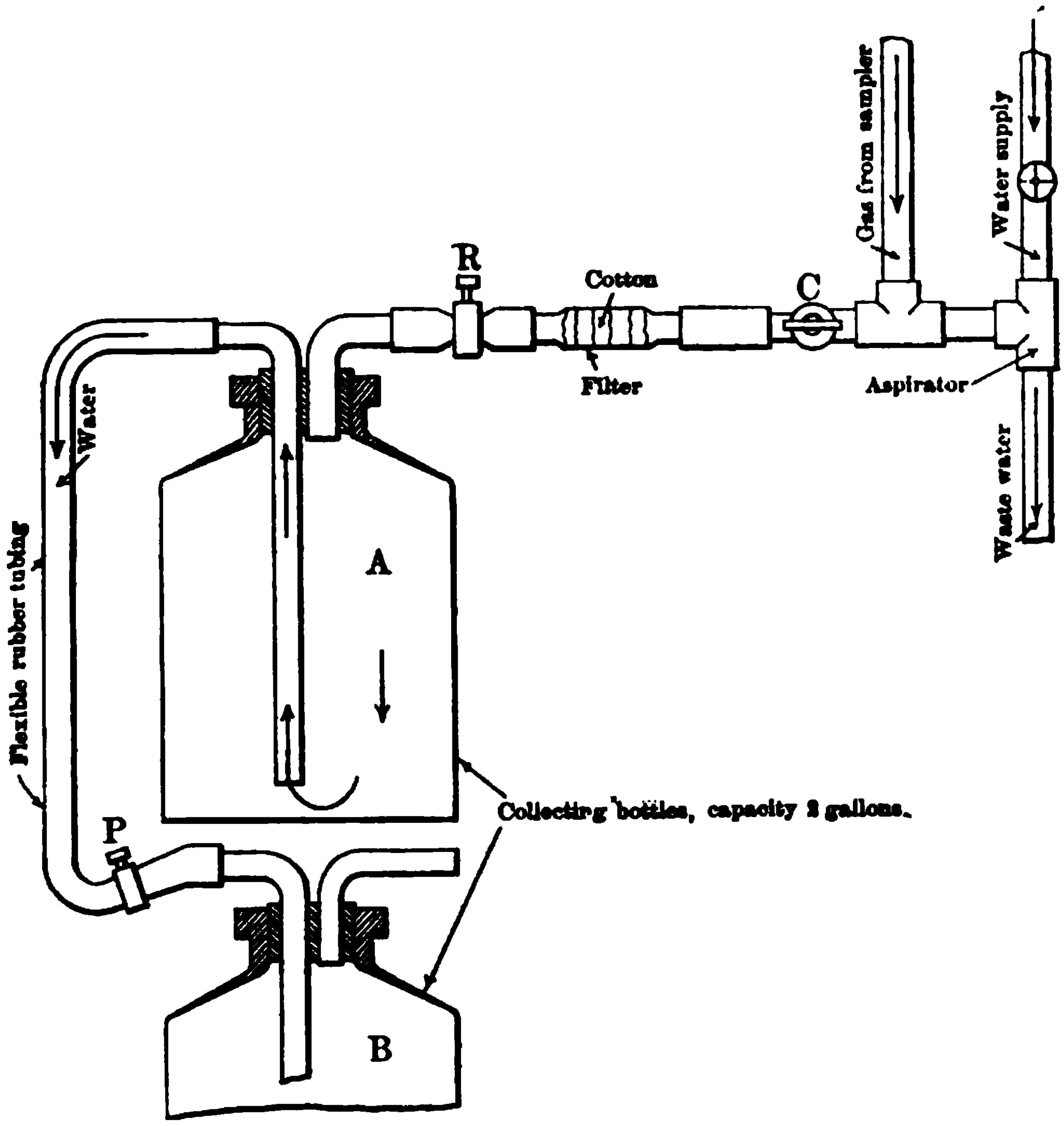

FIGURE 12.—Apparatus for collecting gas samples.

a lower level. As the water level in A dropped, a vacuum was formed above it and the gas rushed in through the filter and the cock C from the continuous stream of gas. The filter was placed in the connections to separate the soot from the gas, thus preventing it from entering and clogging the capillary tubes of the analyzing apparatus. The rate at which the gas flowed into the bottle A could be adjusted by the pinch cock P, so that the time of collecting the gas sample could extend over any desired period. At the end of each period of collecting the sample the pinch cocks P and R and also the cock C were closed, the connections between the filter and the rubber tubing carrying R

were separated, and another pair of collecting bottles was attached and the cocks properly adjusted for the collection of the next sample. The gas sample in A was then forced into an Orsat or other chemical apparatus and analyzed. By these means the average composition for any desired period could be obtained.

The gas-sampling device illustrated in figure 11 is too elaborate, is rather difficult to install, and in a majority of cases would be

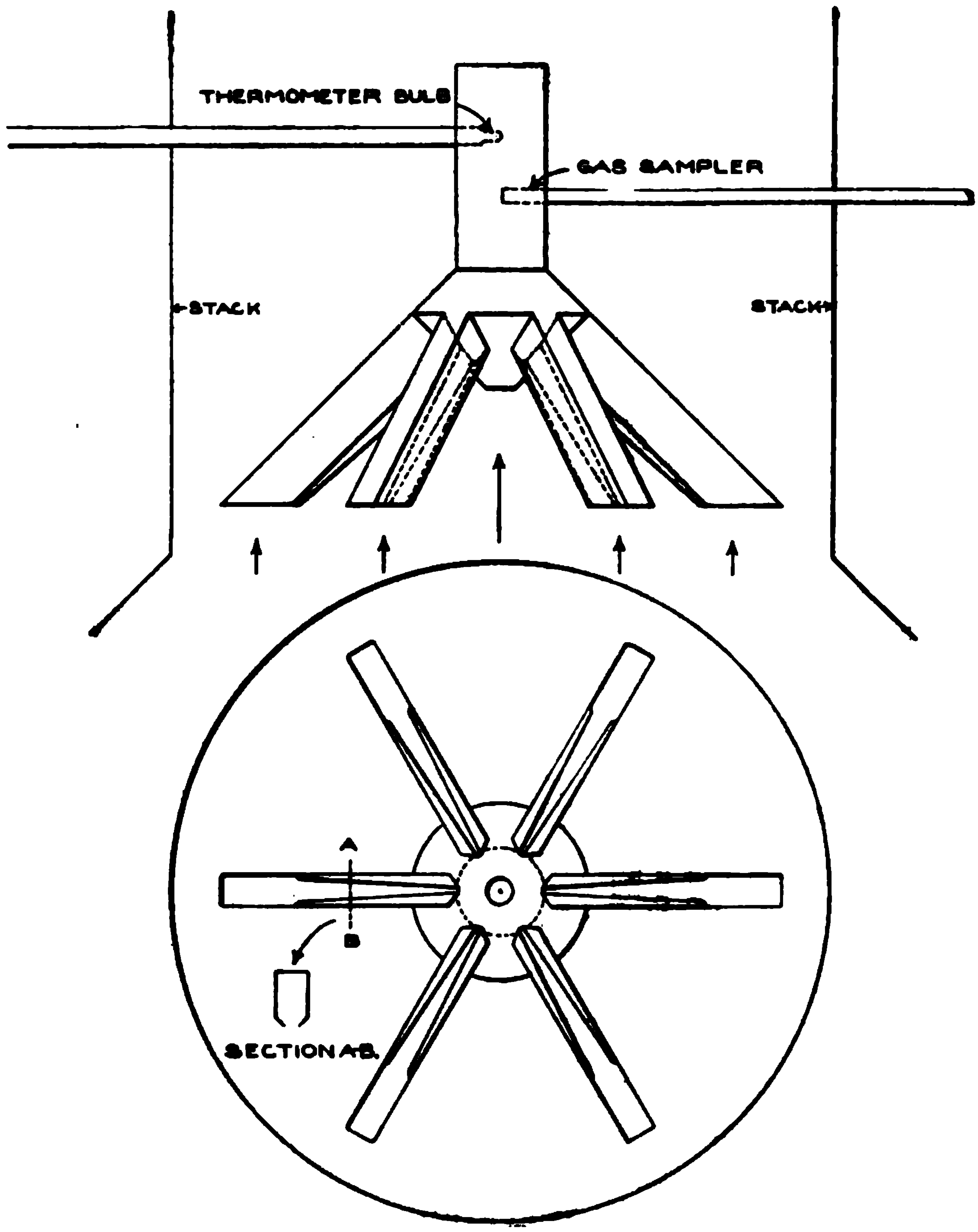

FIGURE 13.—Flue-gas sampler installed in boiler No. 4.

impracticable, therefore a single-tube sampler was placed in the hood and samples drawn from it were analyzed and compared with the samples drawn through the box sampler. The results of these experiments are given and discussed in Part II, page 295. This single-tube sampler was of ½-inch iron pipe 7 feet long, plugged at one end and perforated with $\frac{1}{16}$-inch holes 6 inches apart, the holes being on the side away from the stream of gas to prevent soot from

filling them. The sample of gas was drawn from this sampler by means of an aspirator and two leveling bottles, as described on page 31.

Boiler No. 4 was equipped with the gas-sampling device illustrated in figure 13.

The object of this design of sampler was to obtain gas from various parts of the stack and mix the gas before its temperature was taken and a sample drawn for analysis. The sampler was made of No. 16 sheet iron and consisted of a vertical cylinder 5 inches in diameter, to which were connected, by means of a double-cone shaped body, six scoops making an angle of 45° with the axis of the cylinder. The dimensions of the cross section of these scoops were 2½ by 3 inches. In the bottom of each scoop was a V-shaped opening which diminished toward the center of the sampler, as illustrated in the bottom view of the device in figure 13.

The sampler was placed in the round portion of the stack about 2 feet below the damper, the ends of the scoop being about 4 inches above the top of the hood. The largest diameter of the scoop was about 6 inches smaller than the diameter of the stack. The sample of gas was drawn through a ¼-inch pipe, the end of which was placed in the center of the cylinder. The bulb of a mercury thermometer was also placed in the center of the cylinder about 2 inches above the gas-sampling tube.

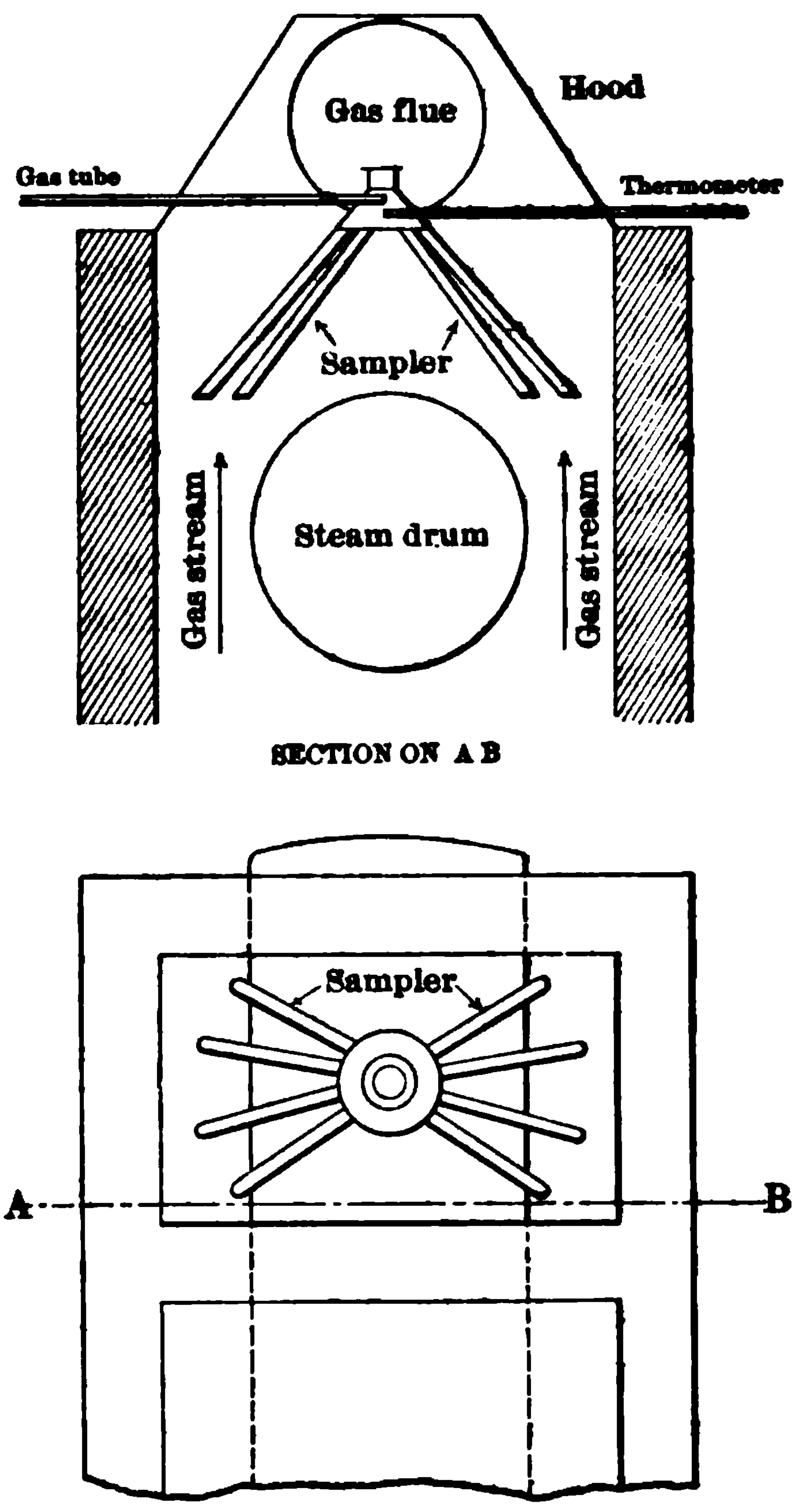

FIGURE 14.—Location and construction of gas sampler in boilers No. 5 and 6.

This construction of the gas sampler permitted accurate determination of the average flue-gas temperatures, as well as the collection of average flue-gas samples. To prevent the cooling of the gases by radiation after they had left the heating surface of the boiler, the hood and the base of the stack were covered with a layer

of asbestos. At the end of five months' service this sampler was found in perfect order in every respect and free from soot inside.

The gas was collected in the same manner as described in connection with figure 12.

The two gas samplers used with boilers Nos. 5 and 6 were constructed on the same principle as the one just described. On account of the exhaust-fan installation, the gas samplers in these two boilers were placed in the rectangular brick flues supporting the hoods. This location necessitated some changes in the details of construction of the samplers. Figure 14 illustrates their location in the flues and their construction. The two samplers were exactly alike. The body of each was a frustum of a cone provided with a bottom and open at the top. Into the bottom were fitted eight cylindrical scoops about 3 inches in diameter and about 3 feet long, which were open only at their ends.

The scoops were so arranged that four of them collected gases from one side of the drum and four from the other side, as illustrated in figure 14. A cap was attached to the top of the cone about 4 inches above the opening. The object of the cap was to screen the thermometer bulb placed in the cone so that the bulb could not radiate heat to the cold sheets of the hood above the sampler. The gas tube and the thermometer were placed in the cone of the sampler, as illustrated in figure 14. The gas tube was extended into the chemical laboratory (see fig. 3) and connected to a water aspirator which induced a continuous flow of gas through the tube. Samples of gas were collected as described on page 31.

ORSAT APPARATUS.

The Orsat apparatus consisted of the usual measuring barrel and three pipettes for the absorbing solutions. The measuring barrel was graduated to 0.2 c. c. The absorption pipettes were provided with flexible rubber sacks which prevented fresh air from coming in contact with the solutions and weakening them. The solutions used were potassium hydroxide for the determination of CO_2, pyrogallic-acid solution in potassium hydroxide for the determination of O_2, and cuprous chloride solution for the determination of CO. The Orsat apparatus is shown in Plate I, *B*.

FLUE-GAS THERMOMETERS.

The mercury thermometers used for the determination of flue-gas temperature had compressed nitrogen gas above the mercury columns and could be used for temperatures up to 1,000° F. The stems were about 30 inches long and were graduated for about 12 inches. These thermometers were made by the Hohmann & Maurer Manufacturing Co.

The recording flue-gas thermometer was essentially an air thermometer. It consisted of an air bulb which was connected by a small copper tube about 50 feet long and about 0.5 mm. in inside diameter to a sensitive pressure gage. The volume of air in the bulb was very large compared to that in the small copper tube. The bulb of the thermometer was placed in the hood, and as the air was heated it expanded and the increase in pressure due to the increase in temperature was transmitted through the tube to the recording gage. The pressures were recorded on a circular sheet of paper which was rotated at a uniform rate by clockwork. The divisions on the circular sheet were such that the temperature in degrees Fahrenheit could be read directly from the records.

PYROMETERS FOR MEASURING FURNACE TEMPERATURE.

At first, attempts were made to obtain regular readings of the furnace temperature by a platinum and platinum-rhodium thermo-couple connected to a millivoltmeter graduated in degrees Fahrenheit. However, the insulating porcelain tubes of the thermo-couple either cracked or were otherwise destroyed by the slagging action of the gases, so that in no test was a complete set of furnace-temperature readings obtained. The thermo-couple was tried with the bare wires exposed to the furnace gases, but the same slagging action reduced the wires and destroyed the couples. Therefore, the method of measuring the furnace temperature by thermo-couples was abandoned.

Later, in 1905, a Wanner optical pyrometer was tried for furnace-temperature measurements and found very satisfactory. A large number of tests were made with a complete set of readings of the temperature in the combustion chamber and several tests with the readings of temperatures in the fuel bed, above the fuel bed, and above the bridge wall. The Wanner optical pyrometer is really a photometer. Its working is based on the relation that exists between the temperature of a hot body and the intensity of the light that the body emits.[a] The temperature is measured by comparing the light emitted by a body whose temperature is to be determined with a light of standard intensity. The standard light is a 6-volt incandescent lamp illuminating a ground-glass surface. A beam of monochromatic (red) light from this source, produced by means of a direct-vision spectroscope and a screen cutting out all but a narrow band in the red, and a similar beam from the hot body whose temperature is to be determined, are passed into a photometric telescope, each beam illuminating one-half of the telescopic field. The photometric comparison is made by adjusting to equal brightness both halves of the

[a] For the theoretical discussion of this subject see Waidner, C. W., and Burgess, G. K., "Optical pyrometry," U. S. Bureau of Standards Bulletin No. 2, 1905, pp. 226-232.

field by means of the polarizing arrangement. The incandescent lamp is supplied with current from a three-cell storage battery. The lamp itself was standardized by comparing it with an amyl-acetate standard lamp.

CALORIMETERS.

For determining the moisture in steam either separating or throttling calorimeters were used. They were of standard construction and were supplied by the Schaefer & Budenberg Company. Steam was sampled with a standard nipple inserted in the vertical section of the steam pipe immediately above the boiler; the calorimeter connection is shown in figure 15 and Plate I, *A*.

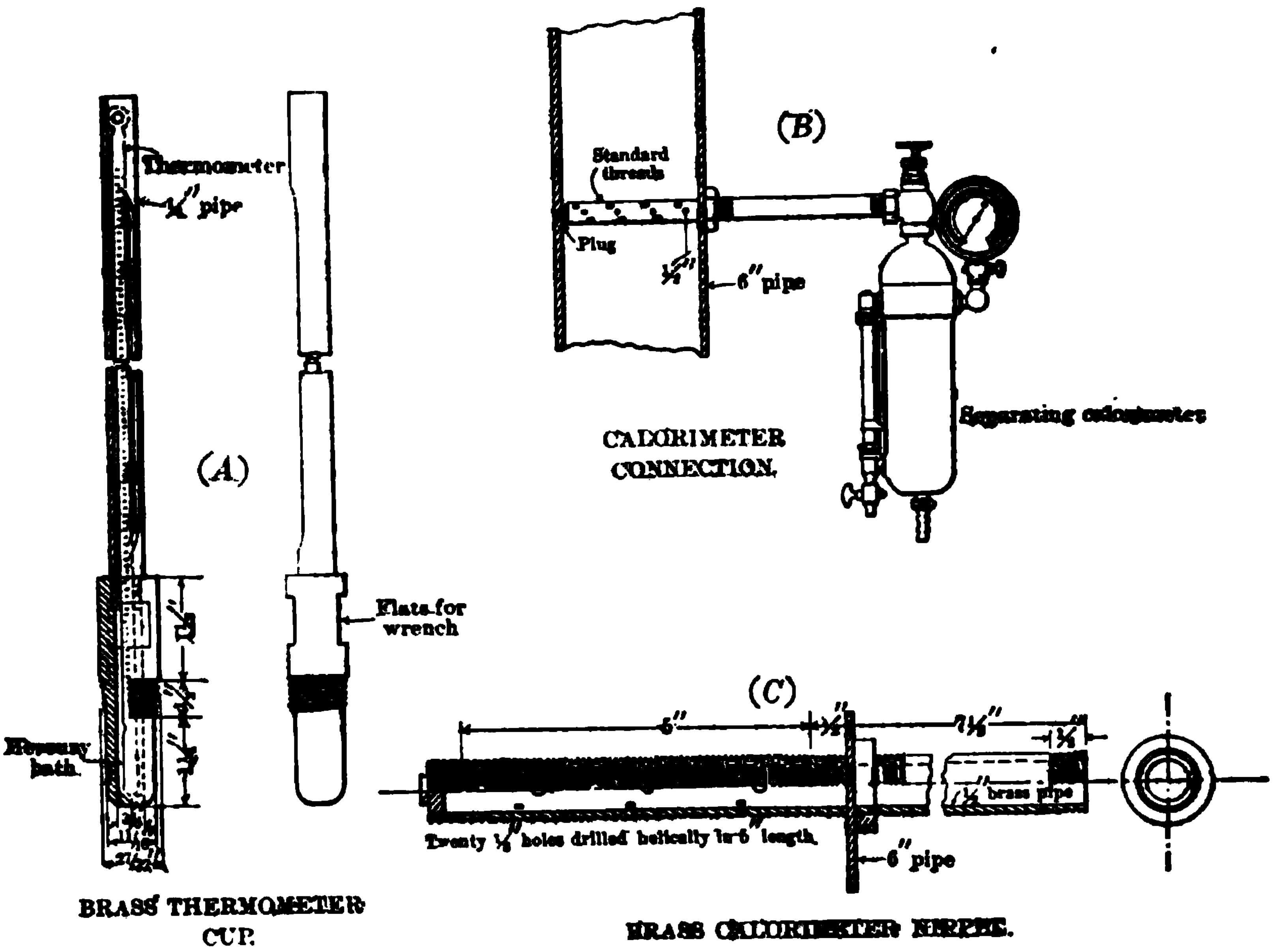

FIGURE 15.—Calorimeter connections and detail of steam-sampling nipple.

DRAFT GAGES.

The draft gages used on all of the tests were of the inclined-tube type and were supplied by the Ellison Draft Gage Company, of Chicago. The liquid used in these gages was light mineral oil, which insured an easy movement of the levels. The scale was so graduated that the gas pressure was indicated directly in inches of water. In addition to the Ellison draft gages, Bristol recording draft gages were used on most of the tests after the first series. These instruments consist of sensitive pressure gages; an ink pen automatically records the intensity of draft in inches of water on a circular sheet of paper which is revolved at a uniform rate by clockwork.

COAL-SIZING SCREEN.

The screen used in sizing the coal consisted of a revolving cylinder of perforated sheet iron of No. 16 gage. The cylinder was 6 feet long and 1 foot in diameter.

The perforations were round holes and ranged from ⅛ inch to 1 inch in diameter. The holes were arranged in circumferential bands, the width of which decreased as the size of holes increased. The band having holes ⅛ inch in diameter was 24 inches wide; the next band had ¼-inch perforations and was 16 inches wide; the following band with ⅜-inch perforations was 10 inches wide; the succeeding band with ½-inch perforations was 9 inches wide; the next band with ¾-inch perforations was 7 inches wide; and the last band having 1-inch perforations was only 6 inches wide. The end of the screen with the smallest perforations was elevated about 6 inches above the other end. The coal entered the screen at the elevated end and by rotation of the screen was gradually conveyed to the lower end. The different sizes were separated by falling through the perforations into special boxes placed under each of the bands.

METHOD OF CONDUCTING THE STEAMING TESTS.

STARTING AND CLOSING THE TESTS.

In starting and closing all the steaming tests the "alternate method" was used. The fires were started from a banked fire between 5 and 6 a. m. and coal was burned at about the same rate as it was to be burned during the test. The steam generated during this preparatory period was disposed of either through the engine or by blowing it directly into the atmosphere. When the furnace was well heated the fire was allowed to burn down to a thickness of 3 to 4 inches and was then leveled with a rake, and the test was started. No particular time was set for starting a test, the governing feature being a favorable condition of the furnace. The start was usually made between 7 and 8 a. m. On starting a test the thickness of the fuel bed was determined by dropping a rake into the fire at several places and noting to what depth the prongs sank into the hot fuel. Record was made also of the steam pressure, the height of water in the boiler and the suction tank, the gas pressures ("drafts") in the furnace and stack, and the load on the boiler.

About 1 to 1½ hours before closing a test the fires were cleaned. An effort was made to burn as much coal after cleaning the fire and before closing a test as was burned after cleaning the fire before a test was started, so that the amount of ash in the fuel bed would be about the same. All the conditions at the close of the tests were made as nearly the same as was practicable; the fires were allowed

to burn down to the same height, the water in the gage glass was brought to the same level, and care was taken that the load on the boiler was the same as it was when the water level was read at the start of the test. The last precaution was important, because the height of water in the gage glass varied considerably with the rate at which the steam left the boiler. If the test was closed with the water level in the boiler a little different from what it was when the test was started, corrections were made at the rate of 340 pounds per inch of water in the gage glass, this quantity being determined by actual calibration with cold water. A scale graduated to a quarter of an inch was permanently attached to the water column, so that height of the water could be readily determined.

In tests made with the Jones underfeed stoker the amount of fuel in the bed could not be estimated as easily as in tests with the hand-fired furnace, inasmuch as the fuel was heaped in the middle of the furnace and a rake or other fire tool could not be used to any advantage. However, by allowing the fire to burn down somewhat at the start and close of a test the error in estimating the fuel was reasonably small.

WEIGHT OF ASH AND REFUSE.

Immediately upon starting a test all the refuse was removed from the ash pit. At the close of a test the ash pit was again cleaned. Ash or refuse taken out of the ash pit or furnace during a test or at the end of it was sampled, weighed, and charged to the test. The sample of the refuse thus collected was quartered and sent to the chemical laboratory for analysis. These statements apply to the hand-fired furnace only. In tests made with the Jones underfeed stoker several methods of determining the weight of ash and refuse were tried, inasmuch at it proved impractical to actually weigh the ash on account of the design of the stoker.

In tests 601 to 605, inclusive, the weight of ash from each test was obtained by weighing the coal and the total refuse for 24 hours and then proportioning the ash among the tests according to the weight of coal burned during each test.

In tests 606 to 608, inclusive, the weight of ash was obtained by actually weighing the ash and refuse made during each test.

In tests 611 to 616, inclusive, the weight of ash was taken as 4.87 per cent of the weight of the coal burned during each test. The above percentage was determined by weighing the coal and the ash for a 36-hour run.

In tests 617 to 619, inclusive, the weight of ash was taken as 7 per cent of the weight of the coal burned during each test. This relation was determined by weighing all the coal and ash for three days.

In the remainder of the tests the ash was figured from the analysis of the coal. The combustible[a] in the refuse was figured from the analysis of a clinker pulled out of the furnace during each test, which clinker was assumed to represent the composition of the refuse of each test.

All the above methods used in the determination of refuse in tests made with the Jones stoker give the weight of ash and refuse only approximately. No great dependence should be put on them.

WEIGHT OF COAL FIRED.

The coal fired was weighed in the previously described charging car which was placed on a platform scale. The coal and car were weighed after each firing and the weight together with the time of each firing were recorded until the car was empty. This record gave the total coal fired and also the amount charged each time. When the charging car was empty a signal was given and readings of the height of water in the boiler and in the suction tank were taken. A sample of coal was taken while the car was being loaded; about two shovelfuls from each car. This sample was kept in a can with a tight cover over night, and the next morning it was quartered and delivered to the chemical laboratory for analysis.

WEIGHT OF FEED WATER AND FEED-WATER TEMPERATURE.

The feed water was weighed in a specially constructed weighing tank having a funnel-shaped top and bottom. The weighing tank discharged the water into the suction tank, from which the injector delivered it to the boiler. The weight of each full tank and the time of emptying the weighing tank were recorded. During the test the feed pump was disconnected from the boiler so that the water could get into the boiler only through the injector. A nipple was taken out of the blow-off pipe so that if any water leaked through it could readily be detected.

The temperature of the feed water was measured with a mercury thermometer placed in the weighing tank. A reading of the temperature was taken every time the tank was emptied.

FLUE-GAS SAMPLING AND FLUE-GAS TEMPERATURE.

Flue gas was sampled with the apparatus described on pages 29 to 34, and collected in 2-gallon leveling bottles by the method described on page 31. Samples were taken for periods of one-half hour on most of the tests and for one-hour periods on the others. Determinations of CO_2, O_2, and CO were made regularly.

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[a] The word "combustible" in this bulletin signifies coal free from ash and moisture.

The temperature of the flue gases was either measured with a mercury thermometer, a reading being taken every 20 minutes, or it was automatically recorded by a Bristol recording air thermometer.

FURNACE TEMPERATURE.

On most of the tests furnace temperatures were taken with a Wanner optical pyrometer. Readings were taken regularly in the rear of the combustion chamber every 20 minutes. On some of the tests special readings were taken of the temperature in the fuel bed, over the fire, above the bridge wall, and at the foot of the bridge wall. For regular readings the pyrometer was standardized every morning; for special readings it was standardized for each set of observations.

GAS PRESSURES ("DRAFTS").

Gas pressures in the hood, above the fuel bed and in the ash pit, were measured on all tests. Ellison differential draft gages were used for this purpose, and readings were taken regularly every 20 minutes. On some of the tests a continuous record of the pressure over the fire was made with a Bristol recording draft gage.

STEAM PRESSURES AND MOISTURE IN STEAM.

Steam pressures were read off a standard pressure gage located on top of the boiler. Regular readings were taken every 20 minutes. On most of the tests pressures were also recorded automatically by a Bristol recording gage.

The moisture in the steam was determined with either a throttling or a separating calorimeter. Determinations of the moisture were made regularly every hour.

DENSITY OF SMOKE.

Observations of smoke were taken over 15-minute periods every two hours when the condition of the fire was fairly representative. Individual readings were taken at 15-second intervals. The density of smoke was estimated by comparison with Ringelmann's smoke charts.

CHEMICAL ANALYSES.

All chemical analyses of coals and refuse were made in the chemical laboratory of the fuel-testing plant under the direction of N. W. Lord. The analyses were made under the immediate supervision of F. M. Stanton.

SIZING OF COAL.

The sample of coal collected during a test weighed about 200 pounds. This sample was roughly halved by quartering and one of

the halves was passed through the sizing screen described on page 37. No attempt was made to take exactly 100 pounds. The coal passing through each set of holes was weighed and recorded, the weight of each size being expressed as a percentage of the total weight of coal screened.

The other half of the coal sample was crushed and further reduced by quartering and delivered to the chemical laboratory.

CLEANING OF BOILERS.

The boilers were kept regularly in a clean condition. The soot was blown off the tubes every day, usually in the morning one or two hours before starting a test. The inside of the boiler was washed with a hose every two or three weeks. The scale was removed from the tubes with a water-turbine cleaner every four or six weeks, and at no time did it average $\frac{1}{32}$ inch in thickness.

RELIABILITY OF OBSERVATIONS.

ERROR IN ESTIMATING THICKNESS OF FUEL BED.

In estimating the thickness of the fuel bed at the beginning and at the end of a test, it was possible to estimate the depth of the fire as 1 inch too thick or 1 inch too thin. One inch in height over 40 square feet of grate represents approximately 3.3 cubic feet. One cubic foot of coked coal weighs about 50 pounds, so that the error in weight might be about 165 pounds. The total weight of dry coal fired was on the average about 8,000 pounds, so that the error in the weight of coal consumed might amount to $\frac{165}{8000}$, or 2 per cent. This represents the probable maximum error from this source. In most tests the error was a great deal smaller.

ERROR IN WEIGHING COAL.

With the platform scale and the charging car the coal could be weighed to within 1 pound. Each load of coal weighed about 700 pounds, so that the error from this source might amount to $\frac{1}{700}$, or 0.14 per cent.

ERROR IN WEIGHT OF REFUSE.

Refuse was taken to mean everything that fell through the grate plus the ash and clinker pulled out of the furnace during the cleanings of the fire. The refuse could be weighed with a possible error of less than 1 per cent. The effect of this error on the economic results of the test would be to increase or decrease by a few pounds the weight of combustible consumed. This error would amount only to a small fraction of a per cent and need not be considered. It is worthy of note that the weight of earthy matter in the refuse from a test was

usually 15 to 20 per cent short of the amount indicated by a chemical analysis of the coal. This difference of 15 to 20 per cent is accounted for by the quantity of refuse and ash carried by the current of gases into the combustion chamber and up the stack.

It may seem improbable that such a large quantity of refuse would be carried away with a total "draft" of less than 1 inch of water. However, if one considers the large quantity of slag and ash that accumulates in the rear of the combustion chamber of a Heine furnace one must admit that even such slow currents of gases carry along with them considerable quantities of ash. This fact was observed not only at the fuel-testing plant, but also at other places. For example, in a series of tests made with the cooperation of the steam engineering section by the Commonwealth-Edison Co., of Chicago, at its Harrison Street Station, it was noticed that a circular opening made in the rear wall of a Heine boiler for the purpose of measuring combustion-chamber temperatures was invariably found filled with ash and cinders every time a reading was taken. The opening in the wall was about 1½ inches in diameter and between temperature readings, which were taken every 30 minutes, was kept closed with a piece of waste. The "draft" was about 0.6 inch in the breaching and about 0.3 inch over the fire. The furnace was served with a chain-grate stoker. The reader may observe similar occurrences for himself in almost any boiler plant.

A test in which the weight of the earthy matter in ash as determined by actual weighing is higher than that calculated from the chemical composition of coal should be looked upon with suspicion. The fact that ash is carried over the bridge wall has been long recognized by the boiler-plant designer, who always provides an ash door in the rear of the boiler setting for the removal of the ash. It is also considered good practice to put ash doors in the bases of all large chimneys, and experience shows that such precautions are always needed. Although these stacks may be connected to the boiler furnaces by long breachings, a considerable quantity of ash is found in their bases every three or four months. It is only the heavier pieces of the ash that are deposited in the rears of the boiler settings and the bases of the stacks; all lighter ash particles are carried out through the stack. The quantity of earthy matter carried away with the gases depends on the character of the ash. The light fluffy ash which results from the burning of some lignitic coals is easily carried away by the slowest current of gas, while a very small percentage of heavy ash containing a large quantity of iron is lost even with a fairly strong "draft."

ERROR IN WEIGHT OF WATER EVAPORATED.

The water could be weighed within less than a pound, so that the error in weighing was insignificant. An error of two or three hundred pounds could have been introduced by not having the same load on the

boiler when reading the height of water in boiler at the beginning as at the end of the test. It may be possible that in extreme cases the water level as observed was 1 inch too high or too low, in which case the error would amount to 340 pounds. However, the total weight of water used during a test was so great that an error of 300 pounds would be only about 0.6 per cent of the total. On account of the effect of the load on the water level in the boiler, it was useless to read the water any closer than to the nearest quarter inch.

ERROR IN FEED-WATER TEMPERATURE.

Feed-water temperature was correct within 2° or 3° F.; this error might possibly affect the final results by 0.1 per cent.

ERROR IN FLUE-GAS SAMPLING.

The sampling of flue gases is a difficult problem in itself. It is not hard to analyze flue gases, but it is difficult to obtain an average sample. The sample collected with the ordinary single-tube sampler is always in error, inasmuch as the composition of gases varies at different places in any one cross section of the gas stream. Moreover, on account of steady leakage into the boiler setting the average gas composition at one cross section of the stream does not represent the average composition of any other cross section. Samples of gas collected with the special sampling devices placed in the hoods of the boilers used in the steaming tests under consideration probably represented closely the average gas composition at the particular cross section at which they were taken. It is estimated that the composition of gas as given in columns 88, 89, and 90, in Table 4 is for most of the tests correct within 5 per cent of itself. In some cases it might be 10 per cent in error, and in a few extreme cases 15 or 20 per cent. This means that if the analysis shows 10 per cent of CO_2, the true CO_2 content might have been either 10.5 or 9.5 per cent in case of a 5 per cent error and 11 or 9 per cent in case of a 10 per cent error. The CO_2 content was always lower in the hood than in the rear of the combustion chamber.

The error in the sampling of the gas does not affect the economic results of tests in any way, excepting that it may mislead the man in charge of the fire; but it affects the heat balance, particularly items 4 and 6.

ERROR IN FLUE-GAS TEMPERATURE.

On tests made with boilers Nos. 1 and 2 the readings of the flue-gas temperature may be considerably in error, due to the fact that no devices were employed to obtain an approximate average temperature and to protect the thermometers from radiation. The readings recorded were generally low and in extreme instances the error is apt to be as much as 100° F.

On account of the special devices placed in the hoods of boilers Nos. 4, 5, and 6, to protect the thermometer bulbs from radiation and to bring streams of gas from different parts of the cross section to scrub against them, the temperatures taken during tests made with these boilers are correct perhaps within 10° F.

The error in the flue-gas temperature does not affect the economic results of the tests, but it does affect the heat balance, particularly items 4 and 6. The causes of the error in the measurements of flue-gas temperature are discussed more fully in Part II, pages 303 to 308.

ERROR IN FURNACE TEMPERATURE.

The furnace temperature readings were obtained with a Wanner optical pyrometer. Most observations were made by looking into the combustion chamber at a point about 2 feet from the rear end and 1 foot below the tile roof. When observing the flame, which was generally done, the indications were perhaps well within 100° F. of the right value. In the absence of flame, light was received from the opposite wall, which was plainly cooler than the gases, as was evident on comparing it by eye with the tile roof near by; and even this latter was cooler than the gases which heated it, because heat was constantly passing upward through the tile into the water tubes. How much too low such readings were could not be determined, perhaps 100° to 200° F. In general, the tests on coals low in volatile matter showed too low combustion temperatures. The error in furnace temperature does not affect the economic results nor the heat balance of the tests.

ERROR IN GAS PRESSURE ("DRAFTS").

The recorded readings of the gas pressures in various portions of the boiler setting are perhaps well within 0.05 of an inch of the true value. The errors in these readings do not affect the economic results nor the heat balance of the tests.

ERROR IN STEAM PRESSURE.

The pressure gauges from which the readings of steam pressure were taken were correct within 2 pounds and could be read within a pound, so that the maximum possible error on any of the tests was about 3 pounds. This error is so inappreciable and its effect on the economic results so small that it does not need any further consideration.

ERROR IN MOISTURE IN STEAM.

The determinations of the moisture in the steam are at the best only approximate, although great care was exercised in taking the readings. Any error that was introduced in these observations was mostly due to the fact that the steam drawn into the calorimeter did not represent the quality of steam flowing through the steam main. The values of the moisture of steam given in Table 4 are perhaps correct within 25 per cent of themselves; that is, if in the table

the moisture in steam is given as 1 per cent, the true value might have been anywhere between 0.75 and 1.25 per cent. The error in the moisture in steam affects the economic results of the tests directly.

ERROR IN DENSITY OF SMOKE.

The smoke observations are perhaps as accurate as can be obtained by means of smoke charts. The values given in Table 4, column 83, under the heading "Smoke (per cent of black)," are reliable and sufficiently accurate for comparison.

ERROR IN CHEMICAL ANALYSIS.

Any errors in the chemical analysis of coal and refuse are largely due to errors in sampling; that is, the chemist's work is accurate, perhaps within a fraction of a per cent, but the sample of coal and the sample of refuse collected were not accurately representative of the true average composition of the coal and ash. Although samples of coal were taken with great care, it is possible that the sample contained 1 per cent more or less ash or 1 per cent more or less moisture than the coal that was burned. Furthermore, on warm days the coal samples lost some moisture while being quartered on the floor of the boiler room; further loss of moisture might have occurred while the quartered sample was being prepared for a moisture determination in the chemical laboratory. It is difficult to ascertain the error due to these causes, but it is possible that the moisture and ash determinations of the coal are 1 per cent too high or too low. The errors in these two determinations affect the heat value of the coal and thereby the economic results of the tests. The first and last items of the heat balance are also directly affected.

The error in the ash analysis is not so serious as that in the coal, although it is more difficult to sample large pieces of clinker than crushed coal, which is more uniform in size. The total weight of refuse in most cases is only a comparatively small percentage of the total coal burned, so that even if the ash analysis were 2 or 3 per cent in error, its effect on the economic results and on the heat balance would only be a fraction of a per cent.

There are probably a few tests in which the errors discussed in the preceding paragraphs are accumulative; that is, tests in which the errors are all in the same direction. In such tests the final results would be 3 per cent too low or too high; hence, in two extreme cases where the errors are accumulative in the opposite directions, tests which actually gave the same results might be represented by data 6 per cent apart. In a majority of the tests these errors are naturally compensating; that is, the various errors have different signs, so that their algebraic sum is close to zero. Of course, in the large number of steaming tests made, it is to be expected that in a few tests the errors are accumulative and the results may be 3 per cent in error.

RESULTS OF TESTS.

The averages of the data and the calculated results of all the regular steaming tests made at the fuel-testing plant to the end of 1908 are given in Table 4. The tests are reported as far as possible in accordance with the recommendations of the American Society of Mechanical Engineers. Some modifications were necessary in order that the complete record of so large a number of tests could be formed into a compact reference table. The tests are arranged alphabetically according to States, and under each State according to the number by which the coal has been designated. If more than one test has been run on the same coal the tests are arranged according to the numbers of the tests. This arrangement facilitates any cross references to the data and results of the tests when the official designation and the number of a test is known. The large number of columns required for tabulating the data for each test necessitated the repetition of the individual test numbers on several subsequent pages. The complete data and results of any individual test will be found by considering in order in one group all the pages on which that test number appears in the identifying columns 1 and 2.

The vertical columns are numbered from 1 to 105. The economic results are given in columns Nos. 75, 76, 77, 79, 81, and 82.

When comparing the results of any group of tests the notes on the individual tests should be consulted. It may be found that poor results were due to unfavorable conditions, or it may be that some of the data are unreliable—a fact that is stated in the notes.

The economic results of the first 20 tests made in 1905 (test No. 101 to test No. 120) are low on account of the poor condition of the boiler setting, which, during the long idleness through the cold winter weather, became leaky. The air that filtered in lowered the CO_2 content and increased the free oxygen in the flue gases. In an attempt to increase the CO_2 content the oxygen supply to the furnace was so reduced that incomplete combustion resulted, which lowered the economic results of these tests. The leaks were not easily detected and the trouble was not discovered until the first few tests were computed and their efficiencies found to be low. Inasmuch as it took several days before analyses of the coal samples were obtained and the tests computed, about 20 tests were made under these conditions. After that the boiler settings were painted and a man was employed almost constantly in keeping them tight.

EXPLANATION OF ITEMS IN TABLE 4 AND METHOD OF COMPUTING THEM.

The items of the tests are given in Table 4 in the vertical columns. Each column has a short heading and is numbered. The numbers in parentheses are those of the code for boiler tests of the American

Society of Mechanical Engineers. The headings only suggest what the vertical columns contain. A full explanation of each item is given in the following paragraphs:

Column 1 gives the serial number of each test. When the steaming tests were started the first test was called test No. 1, the second test was called test No. 2, and so on. The numbers of the tests show in what order the tests were made. There were no tests numbered 79 to 100.

Column 2 gives the name of the State from which the coal came and the number of the coal by which it was designated at the fuel-testing plant. For example, the coals were known at the plant as Alabama No. 1, or Illinois No. 5, and without any reference to the mine or the bed from which the coal was mined.

Column 3 gives the name of the coal bed or seam from which the coal came.

Column 4 gives the name of the place near which the coal bed lies.

Column 5 gives the size of the coal as it was shipped from the mine to the fuel-testing plant. For instance, coal described as "over 1-inch screen," passed over a screen having holes 1 inch square; coal described as "run-of-mine" left the mine in exactly the same size and condition as it was when mined.

Columns 6 to 9, inclusive, give the percentages of the sizes of the coal as fired. These percentages were determined by passing a sample, about 100 pounds, of the coal through the screen described on page 37. Where the figures are missing no sizing tests were made. In the first 78 tests the size of coal was estimated, and in the table is given in percentage of lumps, small coal, and slack.

Column 6 gives the percentage of the coal that went over a screen having round holes 1 inch in diameter.

Column 7 gives the percentage of the coal that went over a screen having round holes ½ inch in diameter, but fell through a screen having round holes 1 inch in diameter.

Column 8 gives the percentage of coal that went over a screen having round holes ¼ inch in diameter, but fell through ½-inch round holes.

Column 9 gives the percentage of the coal that fell through round holes ¼ inch in diameter.

Column 10 gives the average size of the coal or, as it was called, the average diameter. This average diameter as determined is of course only an approximation, but it furnishes a basis on which to compare the size of the coals. The method of determining the average diameter can best be explained by the concrete example following.

Determination of average diameter of coal.

Diameter of holes in screen (inches).	Weight of coal passing through each screen (pounds).		Relative value of each size in determining the average size. (The product of size and weight—column 1 times column 3.)
	Actual.	Reduced to 100-pound basis.	
1	2	3	4
1/8	20	20.4	2.6
1/4	14	14.3	3.6
3/8	18	18.4	6.9
1/2	12	12.2	6.1
3/4	27	27.6	20.7
1	4	4.1	4.1
1½	3	3.0	4.5
....	98	100	48.5

Average diameter $= \frac{4}{100} = 0.485$ inch.

Column 2 of the above table gives the weight of each size as obtained by actual weighing after sizing 98 pounds of coal. Column 3 gives the weight of each size when reduced to a 100-pound basis, or the percentage of each size in the sample. All the coal passing over 1-inch holes is assumed to be 1½ inches in diameter. In determining the average diameter the percentage of each size has a relative value proportional to the diameter which it represents; therefore column 1 is multiplied by column 3. The products are given in column 4. The sum of column 4 divided by 100 gives the average size of the coal. As explained before, this determination of average diameter is only an approximation and has been devised solely for purposes of comparison.

Column 11 gives the appearance of the coal. This item was recorded by the man having charge of the fire, and its correctness depended on his judgment. The item expresses the appearance of coal only in a general way.

Columns 12 and 13 give the state of weather on the day the test was made, and need no further explanation.

Column 14 gives the plant number of the boiler on which the test was made.

Column 15 gives the kind of grate or stoker with which the boiler was equipped.

Column 16 gives the date on which the test was made. The figures indicate, in order, the month, the day of the month, and the year.

Column 17 gives the duration of the test in hours.

Column 18 gives the area in square feet of the grate of the boiler on which the test was made.

Column 19 gives the kind of draft. When the draft was produced by the chimney alone the draft was said to be "natural," when the

pressure fan was used in connection with the stack the draft was said to be "forced," and when the exhaust fans were used the draft was said to be "induced."

Column 20 gives the average barometer reading on the day the test was made. In St. Louis this observation was obtained from the Weather Bureau and no correction was made for the difference in elevation between the Weather Bureau station and the fuel-testing plant, which difference was only a few feet. At the Norfolk plant the barometer readings, reduced to sea level, were also obtained from the Weather Bureau. The plant was only a few feet above sea level, and therefore no corrections were necessary.

Column 21 gives the steam pressure in pounds as read from the steam gauge. The values are arithmetic averages of all the readings of each test.

Column 22 gives the pressure of the gases in the hood below the stack. The figures are arithmetic averages of all the readings taken during each test. The pressure is given in inches of water below atmospheric pressure.

Column 23 gives the pressure of the gases above the fuel bed. The values are arithmetic averages of all the readings taken during each test and are given in inches of water below atmospheric pressure.

Column 24 gives the average air pressure in the ash pit. It was generally 0 (atmospheric pressure), except when the pressure fan was used; then the reading given is in inches of water above atmospheric pressure.

Column 25 gives the temperature of the outside air. The values are arithmetic averages of all the readings taken during each test.

Column 26 gives the average temperature of the boiler room.

Column 27 gives the average temperature of steam during the entire test. The values given in the table were obtained from a steam table and correspond to the average steam pressure given in column 21.

Column 28 gives the average temperature of the feed water for each test, as measured in the weighing tank.

Column 29 gives the average temperature for each test of the feed water entering the boiler after leaving the injector.

Column 30 gives the average temperature of the flue gases, or the temperature of the gases as they leave the heating surfaces of the boiler.

Column 31 gives the average temperature of the furnace. The values given are averages of the readings taken in the rear of the combustion chamber during each test. All readings were taken with an optical pyrometer.

Column 32 gives the total weight of coal consumed during each test. This is the weight of coal as fired, not reduced to a dry basis. The figures given were obtained by actual weighing.

Column 33 gives the total weight of dry coal consumed during each test. The values are computed from the weight of the coal as fired and the moisture in the coal. Column 33 = column 32 × (100 − column 39).

Column 34 gives the total weight of refuse. This includes all the clinkers that were pulled out through the furnace doors and the free ash that fell into the ash pit during the entire test. The figures were obtained by actually weighing the refuse. The method of figuring the weight of ash and refuse from tests on the Jones underfeed stoker is given on pages 38 and 39, under caption "Weight of ash and refuse."

Column 35 gives the percentage of clinker in the total refuse. The clinkers were weighed and their weight was recorded separately. The percentages were obtained by dividing the weight of the clinkers by the weight of the total refuse as given in column 34 and multiplying the quotient by 100. The figure show the clinkering properties of the coals as far as the quantity of clinkers is concerned. It should be kept in mind, however, that the trouble caused by clinkers is by no means proportional to their quantity.

Column 36 gives the weight of the total combustible consumed during the test. The word consumed as used here includes only the combustible that in any form ascends from the grate and does not include the combustible that falls into the ash pit or is pulled out of the furnace with the clinkers during the cleaning of fires. As already stated, the word combustible in this bulletin signifies coal free from ash and moisture. The figures in this column were obtained by subtracting the total weight of refuse from the total weight of dry coal fired.

$$\text{Column } 36 = \text{column } 33 - \text{column } 34.$$

This method of computing the weight of combustible is inaccurate inasmuch as a great deal of earthy matter in the coal is carried over the bridge wall and out through the stack by the current of gases, therefore the earthy matter in the coal as determined by actually weighing the refuse from each test is too low. Consequently all the items in which column 36 is used as a basis are to a certain varying extent incorrect. The figures in this column were computed merely for comparison with the more correct figures given in column 37.

Column 37 gives the total weight of combustible consumed during each test. The values were computed from the chemical analyses of the coal and ash.

$$\text{Column } 37 = \text{column } 32 \times (100 - \text{column } 39 - \text{column } 42) - \frac{\text{column } 34 \times \text{column } 50.}{100}$$

This method of computing the total combustible consumed is more correct than that used in computing column 36.

Column 38 gives the total refuse expressed as a percentage of total dry coal consumed during each test.

$$\text{Column } 38 = \frac{\text{column } 34}{\text{column } 33} \times 100.$$

Columns 39, 40, 41, and 42 give the proximate analyses of the coal as fired. The analyses were made by the chemical division.

The values in column 39 are somewhat uncertain, inasmuch as the small sample of coal used in the chemical determination loses part of its moisture while being prepared from the larger boiler-room sample. On a warm, dry, windy day this loss of moisture is greater than on a cold, damp, and quiet day. In general, it may be said that the moisture as given in column 39 is lower than that in the coal as it was fired.

Values in columns 40 and 41 are based on arbitrary methods of driving off the so-called volatile matter and weighing the residue to determine the fixed carbon and ash. By varying the standard of conditions under which the distillation is effected very different results can be obtained. Thus it can be seen that care should be exercised in deducing results of practical trials from the purely arbitrary results obtained from proximate analyses of dry or moist coal. Coal molecules are probably complex and, although little is known on the subject, it is certain that the products and even the quantities of the products of destructive distillation vary considerably with the method followed, depending on the temperature and rapidity of heating.

Column 43 gives the percentage of sulphur in the coal as fired. This item is separately determined and does not make 100 when added to the four preceding columns, where it is contained mostly, although not entirely, in column 42.

Columns 44, 45, 46, 47, 48, and 49 give the ultimate analysis of the coal reduced to a dry basis. All these items were determined by the chemical division of the fuel-testing plant.

Columns 50 and 51 give the analysis of the refuse. Column 50 gives the percentage of combustible contained in the refuse. Column 51 gives the percentage of real ash or unburnable matter in the refuse.

Column 52 gives the average weight of dry coal consumed per hour.

$$\text{Column } 52 = \frac{\text{column } 33}{\text{column } 17}$$

Columns 53 and 54 give the average weight of the combustible consumed per hour.

$$\text{Column } 53 = \frac{\text{column } 36}{\text{column } 17}$$

$$\text{Column } 54 = \frac{\text{column } 37}{\text{column } 17}$$

The values given in column 54 are more accurate than those given in column 53. (See explanation of columns 36 and 37 and also p. 41 under caption "Error in weight of refuse.")

Column 55 gives the average weight of dry coal fired per square foot of grate area per hour.

$$\text{Column } 55 = \frac{\text{column } 52}{\text{area of grate in square feet}}$$

Columns 56 and 57 give the average weight of combustible consumed per square foot of heating surface per hour.

$$\text{Column } 56 = \frac{\text{column } 53}{\text{total water-heating surface of boiler in square feet}}$$

$$\text{Column } 57 = \frac{\text{column } 54}{\text{total water-heating surface of boiler in square feet}}$$

The values given in column 57 are more accurate than those given in column 56.

Columns 58, 59, 60, and 61 give the heat value of the coal burned on each test. These items were determined by the chemical division.

Column 58 gives the heat value of 1 pound of dry coal determined by actually burning 1 gram of the air-dried coal in oxygen in a Mahler-bomb calorimeter.

Column 59 gives the heat value of 1 pound of combustible figured from the values in columns 58 and 49.

$$\text{Column } 59 = \frac{\text{column } 58}{100 - \text{column } 49}$$

Column 60 gives the heat value of 1 pound of dry coal as figured from the ultimate analysis by Dulong's formula.

$$\text{Column } 60 = \frac{\text{column } 44}{100} \times 14{,}544 + \frac{\text{column } 45 - \left(\frac{\text{column } 46}{8}\right)}{100} \times 62{,}028 + \frac{\text{column } 48}{100} \times 4{,}050$$

In the above equation 14,544 is the heat value in B. t. u. of 1 pound of carbon; 62,028 the heat value in B. t. u. of 1 pound of hydrogen, and 4,050 the heat value in B. t. u. of 1 pound of sulphur.

Column 61 gives the heat value of 1 pound of combustible calculated from the ultimate analysis by Dulong's formula.

$$\text{Column } 61 = \frac{\text{column } 60}{100 - \text{column } 49}$$

Column 62 gives the percentage of moisture in steam. The values were obtained directly from steam-calorimeter determinations.

Column 63 gives the quality of the steam, taking dry saturated steam as unity. In the values given in this column corrections were made for the heat contained in the moisture.

$$\text{Column } 63 = 1 - \frac{\text{column } 62}{100} + \frac{\text{heat in moisture}}{\text{total heat in steam above feed-water temperature}}$$

Column 64 gives the total weight of water fed to the boiler during each test. The values given in this column were obtained by direct weighing of the water, not corrected for moisture in steam.

Column 65 gives the equivalent weight of water if evaporated at 212° F. from feed temperature at 212° F., not corrected for moisture in the steam.

$$\text{Column 65} = \text{column 64} \times \text{column 67}$$

Column 66 gives the total weight of water actually evaporated, corrected for the moisture in the steam.

$$\text{Column 66} = \text{column 64} \times \text{column 63}$$

Column 67 gives the factor of evaporation.

$$\text{Column 67} = \frac{\text{total heat of saturated steam at pressure given in column 21} - \text{heat in water at temperature shown in column 28}}{965.7}$$

Column 68 gives the weight of equivalent water evaporated into dry steam at 212° F. from feed water at 212° F.

$$\text{Column 68} = \text{column 66} \times \text{column 67}.$$

Column 69 gives the weight of water actually evaporated per hour corrected for quality of steam.

$$\text{Column 69} = \frac{\text{column 66}}{\text{column 17}}$$

Column 70 gives the equivalent evaporation per hour.

$$\text{Column 70} = \frac{\text{column 68}}{\text{column 17}}$$

Column 71 gives the average equivalent evaporation per square foot of water-heating surface per hour.

$$\text{Column 71} = \frac{\text{column 70}}{\text{total heating surface of boiler}}$$

Column 72 gives the average boiler horsepower developed during each test. One boiler horsepower has been taken to be equal to the evaporation of 34.5 pounds of water per hour from and at 212° F.

$$\text{Column 72} = \frac{\text{column 70}}{34.5}$$

Column 73 gives the horsepower of the boiler as rated by the builder. This item is the same for all the tests.

Column 74 gives the capacity of the boiler developed on each test, the capacity being expressed as a percentage of the horsepower of the boiler, as rated by the builder.

$$\text{Column } 74 = \frac{\text{column } 72}{210}.$$

Column 75 gives the weight of water in pounds evaporated per pound of coal as fired under actual conditions. The weight of water was not corrected for quality of steam.

$$\text{Column } 75 = \frac{\text{column } 64}{\text{column } 32}$$

Column 76 gives the equivalent evaporation per pound of coal as fired. The weight of water evaporated was corrected for moisture in steam.

$$\text{Column } 76 = \frac{\text{column } 68}{\text{column } 32}$$

Column 77 gives the equivalent evaporation per pound of dry coal The weight of water was corrected for moisture in steam.

$$\text{Column } 77 = \frac{\text{column } 68}{\text{column } 33}$$

Columns 78 and 79 give the equivalent evaporation per pound of combustible calculated by two methods. The weight of water was corrected for moisture in steam. The values given in column 79 are the more accurate.

$$\text{Column } 78 = \frac{\text{column } 68}{\text{column } 36}$$

$$\text{Column } 79 = \frac{\text{column } 68}{\text{column } 37}$$

Columns 80 and 81 give the efficiency of boiler and furnace. This efficiency is the ratio of the heat absorbed by the boiler to the heat of the combustible consumed. The combustible consumed is the combustible ascending from the grate and is equal to the total combustible fired upon the grate minus the combustible falling into the ash pit or pulled out of the furnace door with the clinkers when cleaning fire. As explained in connection with columns 36 and 37, two methods were used in computing this combustible consumed. The furnace and boiler efficiencies have been computed for the combustible obtained by both methods of computation. The values given in column 81 are more accurate than those given in column 80.

$$\text{Column } 80 = \frac{\text{column } 68 \times 965.7}{\text{column } 36 \times \text{column } 59}$$

$$\text{Column } 81 = \frac{\text{column } 68 \times 965.7}{\text{column } 37 \times \text{column } 59}$$

The efficiency given in columns 80 and 81 is the same as item 72 in the American Society of Mechanical Engineers' code for testing boilers, in which it is defined as the quotient of the heat absorbed by the boiler per pound of combustible consumed divided by the heat in 1 pound of combustible.

Column 82 gives the over-all efficiency of the steam-generating apparatus. It is the ratio of the heat absorbed by the boiler to the heat of the coal fired upon the grate. This item includes the efficiency of the grate, the furnace, and the boiler; it is the same as item 73 of the American Society of Mechanical Engineers' code for conducting boiler trials, in which it is defined as the quotient of the heat absorbed per pound of dry coal fired divided by the heat value of 1 pound of dry coal.

$$\text{Column } 82 = \frac{\text{column } 68 \times 965.7}{\text{column } 33 \times \text{column } 58}$$

Column 83 gives the density of smoke in percentages, Ringelmann's chart No. 5 being taken as 100 per cent and chart No. 0 as 0 per cent. Each chart represents a 20 per cent increase. If the average smoke reading corresponded to chart No. 2 the density of smoke was called 40 per cent; if the reading corresponded to chart No. 3½ the smoke was called 70 per cent black.

Column 84 gives the method of firing used on each test.

The spreading method of firing is one in which the charge of coal is spread evenly over the entire grate area.

FIGURE 16.—Method of firing three-door furnace.)

The alternate method of firing is one in which the fresh coal is spread alternately on one-half of the grate area. The alternate firing used on most of the tests was done as shown in figure 16. The furnace had three firing doors. On one firing the parts of the grate marked 1 in the figure were covered with fresh fuel; on the next firing the parts marked 2 were covered, so that only one-half of the grate was distilling gases at a time, and these gases were intermingled with three streams of hot air coming through the uncovered portions of the incandescent fuel bed.

Column 85 gives the average thickness of the fuel bed during each test. The values given in this column are only approximate, as they are merely the estimates of the man in charge of the fire.

Column 86 gives the approximate average intervals between firings. The values given in this table were obtained by dividing the duration of the test by the number of firings; consequently these intervals are somewhat too long, inasmuch as during the cleanings of the fire no coal was fired.

Column 87 gives the approximate average intervals between the leveling or breaking of the fire with a rake or a slice bar. The values given in this column were obtained by dividing the duration of the test by the number of rakings and breakings. The raking and breaking of the fire was recorded by the man in charge of the fire.

Columns 88, 89, 90, and 91 give the average analyses of flue gases. The samples were always collected by one of the special flue-gas samplers described on page 29 under caption "Flue-gas samplers." These samples were collected during a period of either one hour or half an hour. Analyses were made with an Orsat apparatus.

Column 92 gives the weight of the dry gases resulting from burning 1 pound of combustible. The values given in the table were computed from the flue-gas analyses by the following formula:

$$\text{Weight of gas per pound of combustible} = \frac{[11 \times CO_2 + 8 \times O_2 + 7(CO + N_2)] \times \text{per cent carbon in combustible}}{3(CO_2 + CO) \times 100}$$

Or since $CO_2 + O_2 + CO + N_2 = 100$ always.

$$\text{Weight of gas per pound of combustible} = \frac{(4 \times CO_2 + O_2 + 700) \times \text{per cent carbon in combustible}}{3(CO_2 + CO) \times 100}$$

$$\text{Per cent carbon in combustible} = \frac{\text{column 44}}{100 - \text{column 49}}$$

Column 93 gives the heat value of 1 pound of combustible. This is the same item as given in column 59.

Columns 94, 95, 96, 97, 98, and 99 give the heat balance or the distribution of the heat of each pound of combustible consumed during each test.

Column 94 gives the quantity of heat (B. t. u.) absorbed by the boiler per pound of combustible consumed.

$$\text{Column 94} = \frac{\text{column 68} \times 965.7}{\text{column 37}}$$

Column 95 gives the quantity of heat (B. t. u.) carried away by moisture in the coal per pound of combustible consumed.

$$\text{Column 95} = M \times [(212 - \text{column 26}) + 965.7 + (\text{column 30} - 212) \times 0.48]$$

where M is the weight of moisture in pounds accompanying 1 pound of combustible.

$$M = \frac{\text{column 39}}{\text{column 40} + \text{column 41}}$$

Column 96 gives the quantity of heat (B. t. u.) carried away in the moisture formed by burning the hydrogen of the coal per pound of combustible consumed.

Column 96 = 9 H [(212 − column 26) + 965.7 + (column 30 − 212) × 0.48], where H is weight of hydrogen in pounds in 1 pound of combustible.

$$\mathrm{H} = \frac{\text{column } 45}{100 - \text{column } 49}$$

Column 97 gives the quantity of heat (B. t. u.) carried away in the dry gaseous products of combustion per pound of combustible consumed.

Column 97 = column 92 × 0.24 × (column 30 − column 26).

Column 98 gives the quantity of heat (B. t. u.) lost in CO per pound of combustible consumed

$$\text{Column } 98 = \frac{CO}{CO_2 + CO} \times \frac{\text{per cent carbon in combustible} \times 10{,}150}{100}$$

$$\text{Per cent carbon in combustible} = \frac{\text{column } 44}{100 - \text{column } 49}$$

Column 99 gives the quantity of heat (B. t. u.) lost in radiation and other unaccounted-for losses per pound of combustible consumed.

Column 99 = column 93 − (columns 94, 95, 96, 97, and 98)

As this column is obtained by difference, it contains all the errors made in the boiler room and the chemical laboratory. The values given in this column are accurate only within 3 to 5 per cent.

Columns 100, 101, 102, 103, 104, and 105 give all the items of the heat balance expressed as percentages of the heat of 1 pound of combustible.

$$\text{Column } 100 = \frac{\text{column } 94}{\text{column } 93}$$

$$\text{Column } 101 = \frac{\text{column } 95}{\text{column } 93}$$

$$\text{Column } 102 = \frac{\text{column } 96}{\text{column } 93}$$

$$\text{Column } 103 = \frac{\text{column } 97}{\text{column } 93}$$

$$\text{Column } 104 = \frac{\text{column } 98}{\text{column } 93}$$

$$\text{Column } 105 = \frac{\text{column } 99}{\text{column } 93}$$

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation and origin of fuel.			Size of fuel as shipped.	Condition of fuel as fired.						State of weather.	
	Designation of coal.	Designation of bed.	At or near.		Size (per cent).				Average diameter (inches).	Appearance.	Morning.	Afternoon.
					Over 1 inch.	½ to 1 inch.	¼ to ½ inch.	Under ¼ inch.				
1	2	3	4	5	6	7	8	9	10(23)	11	12	13
17	Alabama No. 1	Mary Lee	Horse Creek	Over 1-inch screen	(a)					Bright, clean	Cloudy	Cloudy.
21	do	do	do	do	(b)						Clear	Clear.
16	Alabama No. 2	Jagger	Carbon Hill		(c)					Bright	do	Do.
382	Alabama No. 2-B	do	do	Run of mine	65.4	19.4	6.5	8.7	1.20	Dull black	Cloudy	Partly cloudy.
383	do	do	do	do	48.3	26.7	12.1	12.9	1.04	do	Clear	Clear.
410	do	do	do	do	(d)						do	Do.
390	Alabama No. 3	Underwood	Garnsey	do	19.9	18.6	19.4	42.1	.61	Bright black	Cloudy	Light rain.
394	do	do	do	do	13.7	19.5	19.9	46.9	.54	Dull black	do	Do.
375	Alabama No. 4	Young Blood	Belle Ellen	do	17.1	20.2	22.1	40.6	.60	Dull	Clear	Clear.
376	do	do	do	do	18.1	18.0	17.3	46.6	.58	do	do	Do.
377	do	do	do	do	7.1	12.4	16.8	63.7	.40	Bright	do	Do.
378	do	do	do	do	17.1	19.5	25.2	38.2	.60	do	do	Do.
413	do	do	do	do	(d)						do	Do.
478	Alabama No. 5	Black Creek	Lehigh	do	4.8	13.8	19.5	61.9	.38		Cloudy	Cloudy.
480	do	do	do	do	4.1	15.3	22.7	57.9	.39	Dull	Clear	Clear.
484	Alabama No. 6	Pratt	Dolomite	do	23.9	23.3	17.6	35.2	.76		Light rain	Cloudy.
9	Arkansas No. 1	Huntingdon	Huntingdon	Lump and nut	(e)					Bright	Cloudy	Do.
14	do	do	do	do	(b)						Clear	Clear.
8	Arkansas No. 2	Jenny Lind	Bonanza	do	(f)					Bright	do	Do.
11	do	do	do	do	(b)						do	Do.
29	Arkansas No. 3	do	Jenny Lind	Lump and slack	(g)					Bright, clean	do	Do.
35	do	do	do	do	(b)						do	Do.
40	Arkansas No. 4	Spadra	Denning	Slack	(b)						do	Do.
42	do	do	do	do	(h)						do	Do.
41	Arkansas No. 5	do	Coal Hill	Lump and slack	(i)					Bright	do	Do.
293	Arkansas No. 7A	Hartshorn	Midland	Lump	6.3	11.9	18.5	63.3	.38	Dull	Cloudy	Cloudy, rain.
294	do	do	do	do	7.0	8.8	14.1	70.1	.35	do	do	Clear.
297	Arkansas No. 8		Spadra	1¼-inch screenings	46.6	16.0	8.7	28.7	.92	do	Clear	Cloudy.
308	do		do	do	24.0	17.0	18.0	41.0	.66	Washed	do	
309	do		do	do	15.8	14.5	18.4	51.3	.54	do	do	
340	Arkansas No. 10		Lester	Run of mine	44.4	19.3	15.0	21.3	1.30	Dull, wet	Cloudy	Clear.
75	Colorado No. 1	Laramie	Lafayette	do	(j)					Bright	Clear	Do.

390	Florida No. 1		Orlando	Machined						Brown	Misty	Do.
391	Georgia No. 1	Little River	Menlo	Lump	37.9	15.8	14.5	31.8	.59		Cloudy	Snow.
18	Illinois No. 1	No. 6	O'Fallon	Over 1-inch screen	(k)					Dull	Clear	Clear.
19	Illinois No. 2	do	do	Slack	(i)					Dull, washed	do	Do.
36	Illinois No. 3	No. 7	Marion	Run of mine	(j)					Dull	do	Do.
48	Illinois No. 4	No. 6	Troy	Over 2-inch screen	(m)					do	do	Do.
50	do	do	do	do	(h)					do	Rain	Rain.
73	Illinois No. 6	No. 5	Coffeen	Run of mine	(k)					do	Clear	Clear.
106	Illinois No. 6B	do	do	do	4.7	19.3	21.5	54.5	.42	Washed	do	Do.
313	do	do	do	do	(b)						do	
314	do	do	do	do	(b)						Cloudy	
122	Illinois No. 7C	No. 6	Collinsville	Slack	.0	12.8	18.3	68.9	.30		Clear	Clear.
129	do	do	do	do	.0	10.5	25.5	64.0	.31	Dull, washed		
142	Illinois No. 7D	do	do	Run of mine	33.5	23.3	15.0	28.2	.82	Bright	Fair	Fair.
143	do	do	do	do	32.1	22.0	15.6	30.3	.79	do	Clear	Cloudy.
146	do	do	do	do	24.3	23.3	18.1	34.3	.70	Dull	do	Clear.
516	Illinois No. 7E	do	do	Screened nut	4.8	24.7	25.1	45.4	.47		Cloudy	Do.
101	Illinois No. 8		Paisley	Nut	58.0	21.9	8.7	11.4	1.12		Clear	Do.
102	do		do	do	50.4	25.5	10.6	13.5	1.06	Bright	Cloudy	Cloudy.
103	Illinois No. 9A	No. 6	Staunton	Run of mine							Clear	Do.
104	do	do	do	do							Cloudy	Do.
105	do	do	do	do	33.3	26.0	15.8	24.9	.83	Bright	do	Do.
113	do	do	do	do	24.6	27.8	20.4	27.2	.74	Washed	Clear	Clear.
121	Illinois No. 9B	do	do	Lump	35.7	29.1	15.0	20.2	.89		do	Do.
492	Illinois No. 9C	do	do	Slack	(b)						Cloudy	Do.
107	Illinois No. 10		West Frankfort	do	2.9	23.1	26.4	47.6	.44	Dull, clean	Clear	Do.
108	do		do	do	7.6	19.2	21.1	52.1	.45	do	Cloudy	Rain.
109	do		do	do	22.8	30.1	17.3	29.8	.73		Clear	Clear.
110	do		do	do	19.2	32.6	18.4	29.8	.70		Cloudy	Cloudy.
114	do		do	do	12.8	27.5	23.4	36.3	.60	Washed	Clear	Clear.
137	Illinois No. 11A	No. 7	Carterville	Screenings	21.2	23.6	18.2	37.0	.66	Dull	do	Rain.
138	do	do	do	do	17.4	21.9	15.6	45.1	.59	Bright	do	Clear.
139	do	do	do	do	17.3	19.1	15.8	47.8	.57	Dull	do	Cloudy.
141	do	do	do	do	20.4	25.3	18.5	35.8	.66		do	Clear.
111	Illinois No. 11B	do	do	Run of mine	39.8	25.2	14.5	20.9	.91		do	Cloudy.
112	do	do	do	do	28.9	21.3	17.8	32.0	.75		Cloudy	Do.
115	do	do	do	do	24.6	24.0	18.2	33.2	.71	Bright	Clear	Do.
116	do	do	do	do	40.1	21.6	15.2	23.1	.90		do	
117	do	do	do	Lump	33.6	24.8	16.3	25.3	.83		do	Cloudy.
118	do	do	do	do	20.4	18.2	17.4	44.0	.61	Bright	Cloudy	
119	do	do	do	do	27.6	24.5	18.3	29.6	.76		Clear	Clear.
120	Illinois No. 11C	do	do	¾ to 1⁄16 inch	.0	16.4	45.8	37.8	.40	Bright, clean	do	Do.
312	do	do	do	do	(b)						do	
127	Illinois No. 12	No. 6	Bush	Run of mine	30.8	26.5	17.1	25.6	.81	Dull	Cloudy	Cloudy.
128	do	do	do	do	46.4	21.2	12.3	20.1	.97	do	do	Rain.

a [illegible]
b [illegible]
c [illegible] 30 per cent.
d [illegible] small briquets made by Renfrow machine.
e [illegible] 10 per cent.
f Lump.
g Lump 30 per cent, small coal 30 per cent, slack 40 per cent.
h Small briquets made by Renfrow machine.
i Small coal 30 per cent, slack 70 per cent.
j Small coal 50 per cent, slack 50 per cent.
k Small coal 60 per cent, slack 40 per cent.
l Small coal 20 per cent, slack 80 per cent.
m Lump 90 per cent, small coal 10 per cent.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.—Continued.*

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation and origin of fuel.			Size of fuel as shipped.	Condition of fuel as fired.						State of weather.	
	Designation of coal.	Designation of bed.	At or near.		Size (per cent).				Average diameter (inches).	Appearance.	Morning.	Afternoon.
					Over 1 inch.	½ to 1 inch.	¼ to ½ inch.	Under ¼ inch.				
1	2	3	4	5	6	7	8	9	10(23)	11	12	13
131	Illinois No. 12	No. 6	Bush	Run of mine	23.8	18.1	16.6	41.5	.65		Clear	Cloudy.
133	do	do	do	do	26.4	24.3	17.9	31.4	.74		do	Clear.
135	do	do	do	do	22.5	28.6	24.1	24.8	.74	Washed	Cloudy	Rain.
136	do	do	do	do	15.3	22.9	20.8	41.0	.59	Dull	do	Cloudy.
463	Illinois No. 12B	do	do	Under 3/16 inch	(a)						Clear	Do.
132	Illinois No. 13	do	Benton	1½ to 6 inches	31.0	22.6	15.0	31.4	.77	Bright	do	Do.
134	do	do	do	do	23.8	23.8	20.8	31.6	.71	Dull	do	Clear.
144	do	do	do	do	30.0	27.2	19.0	23.8	.81	Bright, washed	Cloudy	Cloudy.
145	do	do	do	do	25.2	18.7	20.1	36.0	.69	Washed	do	Do.
123	Illinois No. 14	No. 5	Springfield	Lump	23.3	27.9	19.6	29.2	.72	Bright	Clear	Clear.
125	do	do	do	do	30.4	25.2	17.7	26.7	.79		do	Do.
130	do	do	do	do	21.4	27.7	25.0	25.9	.72	Washed	do	Do.
126	Illinois No. 15	No. 6	Centralia	do	20.5	25.9	21.1	32.5	.68	Bright	Cloudy	Do.
152	do	do	do	do	25.5	31.3	21.8	21.4	.78	Dull, washed	Clear	Do.
150	Illinois No. 16	No. 7	Herrin	Lump and egg	48.1	21.0	12.3	18.6	.99	Bright	Rain	
140	Illinois No. 18	No. 2	La Salle	Lump	37.3	22.2	15.9	24.6	.86	Dull	Clear	Do.
148	do	do	do	do	27.1	25.7	17.9	29.3	.75	do	do	Do.
147	do	do	do	do	9.5	25.5	29.6	35.4	.55	Dull, washed	do	Do.
149	do	do	do	do	21.7	22.7	28.8	26.8	.70	do	Hazy	
160	Illinois No. 19A	No. 7	Zeigler	¾ inch	.0	21.3	32.0	46.7	.39	Dull	Clear	Do.
161	do	do	do	do	.0	13.6	27.2	59.2	.33	do	Hazy	Hazy.
163	do	do	do	do	.0	17.7	34.7	47.6	.38	do	Clear	Clear.
170	do	do	do	do	.0	13.6	31.3	55.1	.34	do	do	Do.
171	do	do	do	do	.0	13.6	31.8	54.6	.34	do	Cloudy	Rain.
175	Illinois No. 19B	do	do	3-inch	60.2	15.7	9.2	14.9	1.10	Bright		
204	do	do	do	do	44.0	17.2	12.3	26.5	.91	do		
205	do	do	do	do	54.4	15.1	10.7	19.8	1.03	do	Foggy	Clear.
420	Illinois No. 19C	do	do	Run of mine	20.2	24.2	19.1	36.5	.66	do	Clear	Partly cloudy.
423	do	do	do	do	15.8	19.5	18.3	46.4	.57		do	Do.
424	Illinois No. 19D	do	do	Lump	23.9	24.5	18.7	32.9	.71	Bright	do	Clear.
425	do	do	do	do	37.9	27.4	15.0	19.7	.91	do	do	Partly cloudy.
421	Illinois No. 19E	do	do	1¼-inch	18.0	45.9	16.6	19.5	.78	do	Cloudy	Do.
422	do	do	do	do	14.4	44.0	17.8	23.8	.72		Partly cloudy	Do

292	Illinois No. 20	No. 6	Staunton	Screenings	20.1	22.9	18.7	38.3	.64	Dull black	Cloudy	Cloudy.
301	do	do	do	do	17.1	27.7	23.7	31.5	.66	Washed		
302	do	do	do	do	22.5	28.1	21.9	27.5	.73	do		
315	Illinois No. 21	do	Troy	Lump	34.0	21.3	18.1	26.6	.81	Bright	Clear	
316	do	do	do	do	33.6	20.6	16.2	29.6	.80	do	do	Clear.
318	do	do	do	do	(b)						do	Do.
324	Illinois No. 22A	do	Marysville	do	84.6	5.8	3.5	6.1	3.46	Dull	Snow	Snow.
325	do	do	do	do	87.4	5.4	2.6	4.6	3.56	do	Clear	Clear.
328	do	do	do	do	34.1	27.0	22.0	16.9	.87	Washed	Cloudy	Partly cloudy.
306	Illinois No. 23A	do	Donkville	do	37.3	19.5	16.2	27.0	.85	Dull	Clear	Clear.
317	do	do	do	do	18.9	26.7	24.3	30.1	.68	Washed	do	Do.
321	Illinois No. 23B	do	do	Slack	(b)						do	
322	do	do	do	do	(b)							Clear.
335	Illinois No. 24B	do	New Baden	Lump	49.7	19.9	12.4	18.0	1.00	Bright	Clear	Cloudy.
336	do	do	do	do	22.1	25.2	19.6	33.1	.69	Bright, black	Cloudy	Snow.
337	do	do	do	do	92.0	3.2	1.6	3.2	1.88	Dull, wet		Do.
338	Illinois Nos. 25A and 25B.	do	Germantown	Run of mine and lump.	61.4	14.3	9.1	15.2	1.99	Dull	Clear	Clear.
339	do	do	do	do	82.4	7.2	4.0	6.4	2.17	Dull, dirty	do	Do.
341	Illinois No. 26	No. 5	Lincoln	Run of mine	78.5	8.9	4.4	8.2	2.17	Bright	Cloudy	Cloudy.
342	do	do	do	do	78.1	9.2	5.8	6.9	2.59	Dull	do	Clear.
353	Illinois No. 27	No. 6	Auburn	do	72.4	11.1	6.8	9.7	2.29	do	Light rain	Do.
354	do	do	do	do	34.6	25.7	17.6	22.1	.93	Dull, wet	Misty	Cloudy.
459	Illinois No. 28A	No. 7	Herrin	$\frac{1}{16}$-inch screenings	(c)					Washed	Clear	Clear.
457	Illinois No. 28B	do	do	Screenings	(c)						Cloudy	Do.
448	Illinois No. 28C	do	do	Lump	32.3	22.1	13.7	31.9	.79	Bright	Partly cloudy	Cloudy.
452	do	do	do	do	58.4	21.3	9.0	11.3	1.12		Clear	Clear.
465	Illinois No. 29A	No. 5	Livingstone	Screenings	(c)					Washed	Cloudy	Light rain.
460	Illinois No. 29B	do	do	Run of mine	34.1	21.5	13.2	31.2	.81	Bright	Partly cloudy	Clear.
461	do	do	do	do	51.4	22.4	10.7	15.5	1.04	do	Clear	Do.
466	do	do	do	do	(a)						Misty	Cloudy.
511	Illinois No. 30	No. 7	Shiloh	Nut	(b)					Washed	Cloudy	Do.
489	Illinois No. 31	No. 6	Warden	Screenings	(b)						Partly cloudy	Partly cloudy.
491	do	do	do	do	(a)						Cloudy	Clear.
513	Illinois No. 33	No. 7	Trenton	do	(b)						do	Cloudy.
509	Illinois No. 34B	No. 5	Harrisburg	Run of mine	44.3	22.8	13.4	19.5	1.23		Partly cloudy	Clear.
71	Indiana No. 1	No. 6	Mildred	do	(b)					Washed	Cloudy	Cloudy.
68	do	do	do	do	(d)					Dull, washed	Clear	Clear.
65	Indiana No. 2	No. 5	Booneville	do	(e)					Dull	do	Do.
162	Indiana No. 3	do	do	Nut and slack	28.4	25.8	16.4	29.4	.77	do		
151	Indiana No. 4		Star City	Screenings	36.5	21.0	15.4	27.1	.84	Dull, dirty	Cloudy	Clear.
165	do		do	do	19.0	22.4	18.6	40.0	.63	do	Clear	Do.
166	do		do	do	8.1	18.3	18.8	54.8	.45	do	do	Rain.
154	do		do	do	18.5	29.9	24.4	27.2	.69	Dull, washed	do	
153	Indiana No. 5	No. 5	Hymera	Run of mine	29.0	23.2	16.2	31.6	.76	Dull	do	Clear.
155	do	do	do	do	27.7	20.0	20.4	31.9	.73	do	do	Do.
156	do	do	do	do	33.7	23.2	15.4	27.7	.82	do	Cloudy	Rain.
157	Indiana No. 6	No. 4	do	do	29.9	19.9	14.2	36.0	.74	do	Clear	Clear.

[a] Small briquets made by Renfrow machine.
[b] Large briquets made by English machine.
[c] Large briquets made by English machine and small briquets made by Renfrow machine.
Small coal 50 per cent, slack 50 per cent.
[e] Small coal 70 per cent, slack 30 per cent.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation and origin of fuel.			Size of fuel as shipped.	Condition of fuel as fired.						State of weather.	
	Designation of coal.	Designation of bed.	At or near.		Size (per cent).				Average diameter (inches).	Appearance.	Morning.	Afternoon.
					Over 1 inch.	$\frac{1}{2}$ to 1 inch.	$\frac{1}{4}$ to $\frac{1}{2}$ inch.	Under $\frac{1}{4}$ inch.				
1	2	3	4	5	6	7	8	9	10(23)	11	12	13
159	Indiana No. 6	No. 4	Hymera	Run of mine	39.8	27.1	15.8	17.3	.93	Dull, washed	Clear	Clear.
158	Indiana No. 7A	No. 5	Littles	Lump	44.3	25.0	14.2	16.5	.97	Bright	do	Do.
288	do	do	do	do	(a)						do	Do.
164	Indiana No. 7B	do	do	Screenings	5.6	25.3	25.8	43.3	.49	Dull	Cloudy	
176	do	do	do	do	5.1	23.1	24.4	47.4	.46	do	Clear	Clear.
182	Indiana No. 8		Terre Haute	Lump	30.5	23.1	16.7	29.7	.78	do	do	Do.
183	do		do	do	39.5	23.3	13.4	23.8	.89	do	do	Do.
185	do		do	do	27.7	21.4	17.2	33.7	.73	do	Cloudy	Cloudy.
184	do		do	do	20.1	29.9	24.3	25.7	.71	Dull, washed	Rain	Do.
168	Indiana No. 9A	No. 7	Macksville	do	40.6	24.2	15.0	20.2	.92	Dull	Clear	Do.
169	do	do	do	do	31.2	21.6	16.0	31.2	.78	do	Cloudy	Do.
174	Indiana No. 9B	do	do	Run of mine	23.8	21.7	18.2	36.3	.68	do	do	Do.
334	Indiana Nos. 9A and 9B	do	do	Lump and run of mine.	(a)						Partly cloudy.	Rain.
167	Indiana No. 10	No. 6	Rosedale	Lump	27.5	25.8	19.2	27.5	.76	Bright, clean	Cloudy	Clear.
177	do	do	do	do	26.2	33.6	24.6	15.6	.81	Bright, washed	Clear	Do.
233	Indiana No. 11	No. 4	Dugger	do	27.4	25.1	18.6	28.9	.76	Dull		
234	do	do	do	do	22.1	19.9	19.2	38.8	.65	do		
235	do	do	do	do	20.8	19.0	19.4	40.8	.63			
299	Indiana No. 12	No. 5	Hartwell	Run of mine	27.5	21.8	18.3	32.4	.74	Dull		
300	do	do	do	do	30.5	24.3	18.9	26.3	.80			
310	do	do	do	do	28.9	24.8	23.6	22.7	.80	Washed	Cloudy	Clear.
432	Indiana No. 13	No. 6	Terre Haute	do	46.5	21.1	12.7	19.7	1.33		Partly cloudy.	Cloudy.
433	do	do	do	do							Cloudy	
430	Indiana No. 14	No. 3	Seelyville	do	67.3	15.4	8.0	9.3	1.68	Bright	Clear	Cloudy.
431	do	do	do	do	36.9	18.7	14.2	30.2	1.13		do	Clear.
428	Indiana No. 15	No. 4	Linton	do	44.6	21.2	12.1	22.1	1.03		Cloudy	Cloudy.
429	do	do	do	do	33.9	19.5	13.4	33.2	.85		do	Partly cloudy.
426	Indiana No. 16	No. 5	do	do	38.0	21.8	14.0	26.2	.86		Partly cloudy.	Cloudy.
427	do	do	do	do	27.1	25.3	17.0	30.6	.76		Clear	Partly cloudy.
441	Indiana No. 17	do	Bicknell	do	47.3	26.9	13.6	12.2	1.20		Cloudy	Clear.
442	do	do	do	do	16.8	22.7	18.0	42.5	.60		Clear	Do.
435	Indiana No. 18B	do	Ayrshire	Lump	30.4	17.4	21.8	30.4	.77	Bright	Cloudy	Do.

436	do	do	do	do	45.1	23.5	12.8	18.6	.97	do	do	Cloudy.
464	Indiana No. 19	Brazil block	Diamond	Screenings	(b)						Clear	Clear.
10	Indian Territory No. 1		Henryetta	Lump and slack	(c)					do	do	Do.
20	Indian Territory No. 2	Hartshorne	Hartshorne	Run of mine	(d)					do	do	Do.
417	Indian Territory No. 2D	do	do	[illegible]-inch slack	25.2	27.6	18.7	28.5	.75		Partly cloudy	Partly cloudy.
418	do	do	do	do	25.5	31.4	18.6	24.5	.78		do	Cloudy.
455	do	do	do	do	(b)						Clear	Clear.
453	do	do	do	do	(e)						Partly cloudy	Cloudy.
456	do	do	do	do	(a)					Washed	Cloudy	Do.
32	Indian Territory No. 3	McAllester	Edwards	Run of mine	(d)					Bright	do	Clear.
52	Indian Territory No. 4	do	Lehigh	Over 1-inch screen	(f)					do	do	Cloudy.
437	Indian Territory No. 8				(e)					Washed	Clear	Do.
449	Indian Territory No. 9		Panama	Run of mine	7.5	8.1	12.4	72.0	.35	Bright	do	Clear.
450	do		do	do	(e)						do	Do.
45	Iowa No. 1	Third Seam	Laddsdale	do	(g)					Dull	Cloudy	Cloudy.
67	Iowa No. 2	Big Vein		do	(d)					Very dirty	do	Do.
49	Iowa No. 3	Third Seam	Altoona	Lump	(h)					Dull	Clear	Clear.
47	Iowa No. 4	Mystic	Centerville	do	(i)					do	do	Do.
66	do	do	do	do	(a)						do	Do.
55	Iowa No. 5			Run of mine	(j)					Medium bright	do	Do.
601	Jamestown No. 1	Jaw Bone	Virginia City, Va.	do							do	Do.
602	do	do	do	do							do	Do.
603	Jamestown No. 3	Pocahontas	Davy, W. Va.	do							do	Do.
604	do	do	do	do							do	Partly cloudy.
605	do	do	do	do							do	Clear.
606	do	do	do	do							Cloudy	Do.
607	do	do	do	do							do	Light rain.
608	Jamestown No. 4	Fire Creek	Rush Run, W. Va.	do							do	Clear.
609	do	do	do	do							Clear	Do.
610	do	do	do	do							do	Do.
611	do	do	do	do							do	Do.
612	do	do	do	do							Cloudy	Do.
613	do	do	do	do							Clear	Do.
614	do	do	do	do							do	Do.
615	do	do	do	do							do	Do.
616	do	do	do	do							do	Do.
617	do	do	do	do							do	Do.
618	do	do	do	do							do	Do.
619	do	do	do	do							do	Do.
627	Jamestown No. 6	Sewell	Red Star, W. Va.	do							do	Do.
630	do	do	do	do								
631	do	do	do	do								
620	Jamestown No. 7	do	Derry Hale, W. Va.	do							Cloudy	Clear.
621	do	do	do	do							Partly cloudy	Do.
623	do	do	do	do							Clear	Do.
624	do	do	do	do							Partly cloudy	Do.
625	do	do	do	do							Cloudy	Light rain.

a Large briquets made by English machine.
b Large briquets made by English machine, and small briquets made by Renfrow machine.
c Lump 20 per cent, small coal 40 per cent, slack 40 per cent.
d Small coal 50 per cent, slack 50 per cent.
e Small briquets made by Renfrow machine.
f Small coal 60 per cent, slack 40 per cent.
g Small coal 80 per cent, slack 20 per cent.
h Small coal 70 per cent, slack 30 per cent.
i Lump 30 per cent, small coal 50 per cent, slack 20 per cent.
j Small coal 65 per cent, slack 35 per cent.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation and origin of fuel.			Size of fuel as shipped.	Condition of fuel as fired.						State of weather.	
	Designation of coal.	Designation of bed.	At or near.		Size (per cent).				Average diameter (inches).	Appearance.	Morning.	Afternoon.
					Over 1 inch.	½ to 1 inch.	¼ to ½ inch.	Under ¼ inch.				
1	2	3	4	5	6	7	8	9	10(23)	11	12	13
626	Jamestown No. 7	Sewell	Derry Hale, W. Va.	Run of mine							Clear	Clear.
639	Jamestown No. 11	Beckley	West Raleigh, W. Va.	do								
6	Kansas No. 1	Lower Weir-Pittsburg	Fleming	do	(a)					Dull	do	Do.
7	do	do	do	do	(b)					do	do	Do.
5	Kansas No. 2	do	Yale	Lump and nut	(c)					do	do	Do.
13	do	do	do	do	(d)					Dull, washed	Rainy	Cloudy.
488	Kansas No. 2B	do	do	Slack	(e)						Clear	Clear.
487	do	do	do	do	(f)						do	Do.
495	do	do	do	do	(f)					Washed	Cloudy	Light rain.
3	Kansas No. 3	do	Scammon	Run of mine	(g)					Dull	Clear	Clear.
4	do	do	do	do	(h)					do	do	Do.
58	Kansas No. 4	do	Atchison	Lump	(i)					Bright	do	Cloudy.
72	Kansas No. 5	do	West Mineral	Lump and nut	(j)					do	Cloudy	Clear.
311	Kansas No. 6	do	Jewett	Lump	42.8	21.4	13.7	22.1	.92		Partly cloudy	Cloudy.
323	do	do	do	do	38.7	25.3	17.7	18.3	.91	Washed	Light rain	Rain.
60	Kentucky No. 1	Straight Creek	Straight Creek	Run of mine	(k)					Very clean	Clear	Clear.
255	Kentucky No. 1C	do	do	1½-inch slack	21.1	26.7	20.0	32.2	.69	Dull		
263	do	do	do	do	18.4	22.2	21.2	38.2	.62			
265	do	do	do	do	35.8	24.4	17.0	22.8	.86	Dull		
57	Kentucky No. 2	No. 11	Earlington	Run of mine	(l)					Bright	Clear	Clear.
76	do	do	do	do	(f)						Rainy	Rainy.
64	Kentucky No. 3	No. 9	Barnsley	½ run of mine, ½ lump and nut.	(l)					Bright	Clear	Clear.
62	Kentucky No. 4	No. 11	Wheatcroft	Run of mine	(l)					do	do	Do.
276	Kentucky No. 5	High Splint	Big Black Mountain.	do	67.5	11.6	7.4	13.5	1.17			
277	do	do	do	do	54.4	14.7	11.8	19.1	1.03			
270	Kentucky No. 6	No. 1	Paintsville	do	62.6	16.5	9.4	11.5	1.14	Dull	Cloudy	Snow.
271	do	do	do	do	62.2	14.1	7.6	16.1	1.12	do		
278	Kentucky No. 7	No. 9	Central City	Lump	26.8	24.7	20.6	27.9	.76	do		
279	do	do	do	do	36.1	24.1	7.4	32.4	.84	do	Cloudy	Rain.
434	Kentucky No. 8	"Bell Coal"	Sturgis	Run of mine	29.9	23.4	15.0	31.1	.77		do	Light rain.

443	....do..........	....do..........	....do..........	....do..........	27.7	20.0	15.4	36.3	.80	Dull..........	Clear..........	Clear.
462	Kentucky No. 9B......	No. 9..........	McHenry..........	....do..........	32.3	26.4	16.6	24.7	.83	Bright..........	....do..........	Do.
222	Maryland No. 1..........		Westernport..........	....do..........	5.2	6.9	14.5	73.4	.34	Bright, clean..........	Cloudy..........	Cloudy.
231	....do..........		....do..........	....do..........	17.2	21.2	22.2	39.4	.61	Bright, washed...	Clear..........	Clear.
232	....do..........		....do..........	....do..........	15.7	14.7	17.3	52.3	.53	Washed..........	Cloudy..........	Cloudy.
490	Maryland No. 2..........	Pittsburg..........	Frostburg..........	....do..........	17.4	20.8	20.2	41.6	.60	Bright..........	....do..........	Do.
493	....do..........	....do..........	....do..........	....do..........	(f)						....do..........	Light rain.
518	....do..........	....do..........	....do..........	....do..........	(e)						Light rain....	Clear.
12	Missouri No. 1..........		New Home..........	....do..........	(a)					Dull..........	Rainy..........	Cloudy.
23	....do..........		....do..........	....do..........	(f)						Clear..........	Clear.
15	....do..........		....do..........	....do..........	(d)					Dull, washed.....	....do..........	Do.
37	Missouri No. 2..........	Bevier..........	Bevier..........	....do..........	(j)					Dull..........	Clear..........	Cloudy.
44	....do..........	....do..........	....do..........	....do..........	(j)					....do..........	....do..........	Clear.
78	Missouri No. 3..........	Mendota..........	Mendota..........	Screenings..........	(d)					....do..........	Cloudy..........	Cloudy.
77	....do..........	....do..........	....do..........	....do..........	(j)					....do..........	Clear..........	Clear.
70	Missouri No. 4..........		Versailles..........	Run of mine..........	(i)					....do..........	Cloudy..........	Cloudy.
319	Missouri No. 5..........		Higbee..........	....do..........	23.5	22.9	19.3	36.3	.69	....do..........	....do..........	Clear.
320	....do..........		....do..........	....do..........	20.1	21.0	18.8	40.1	.63	....do..........	Clear..........	Do.
326	Missouri No. 6..........		Huntsville..........	Lump..........	36.5	23.3	16.6	23.6	.86	....do..........	....do..........	Do.
327	....do..........		....do..........	....do..........	(m)	(m)	12.0	15.7	1.17	....do..........	Cloudy..........	Light rain.
329	Missouri No. 7A..........		Novinger..........	No. 1 nut..........	47.0	21.6	14.9	16.5	.99	Washed..........	....do..........	Rain.
330	....do..........		....do..........	....do..........	46.3	23.2	15.0	15.5	.99	....do..........	Clear..........	
332	Missouri No. 7B..........		....do..........	No. 2 nut..........	21.4	43.6	21.4	13.6	.82	....do..........	....do..........	Clear.
486	Missouri No. 10..........	Bevier..........	Bevier..........	Screenings..........	(n)						Cloudy..........	Light rain.
470	Montana No. 2..........		Fromberg..........	Run of mine..........	38.2	24.1	13.7	24.0	.89		Clear..........	Clear.
477	Montana No. 3..........		Bridger..........	....do..........	52.9	21.6	10.9	14.6	1.46		Cloudy..........	Cloudy.
27	New Mexico No. 1......	Nos. 3 and 3½..........	Gallup..........	Lump and slack...	(o)						Clear..........	Clear.
26	New Mexico No. 2......	Otero & Thatcher...	....do..........	Slack..........	(d)					Dull..........	....do..........	Cloudy.
30	....do..........	....do..........	....do..........	....do..........	(e)						....do..........	Clear.
396	New Mexico No. 3A.....	Main Raton..........	Van Houten..........	Run of mine..........	14.8	23.2	22.2	39.8	.59	Dull..........	Partly cloudy.	Do.
389	New Mexico No. 3B.....	....do..........	....do..........	Lump..........	30.6	27.1	18.3	24.0	.82	....do..........	Clear..........	Do.
391	....do..........	....do..........	....do..........	....do..........	34.5	27.9	16.8	20.8	.87	....do..........	....do..........	Do.
392	....do..........	....do..........	....do..........	....do..........	5.6	27.9	31.3	35.2	.53	Washed..........	Cloudy..........	Do.
397	New Mexico No. 4A.....	....do..........	Brilliant..........	Run of mine..........	21.3	23.2	18.8	36.7	.66	Bright..........	....do..........	Partly cloudy.
398	....do..........	....do..........	....do..........	....do..........	17.4	21.6	25.2	35.8	.62	Washed..........	Clear..........	Clear.
395	New Mexico No. 4B.....	....do..........	....do..........	Slack..........	1.7	17.8	27.4	53.1	.39	Dull..........	Light rain.....	Cloudy.
387	New Mexico No. 5.....	....do..........	Blossburg..........	Run of mine..........	21.2	19.9	20.8	38.1	.64	....do..........	Partly cloudy.	Light rain.
33	North Dakota No. 1....		Lehigh..........	Screenings..........	(i)					Brown..........	Clear..........	Cloudy.
206	North Dakota No. 3....	No name..........	Wilton..........	Lump..........	76.5	10.6	4.9	8.0	2.42	Dull brown..........	....do..........	
191	Ohio No. 1..........	No. 4..........	Wellston..........	Run of mine..........	19.3	22.4	19.4	38.9	.63	Dull..........	Cloudy..........	Clear.
192	....do..........	....do..........	....do..........	....do..........	37.9	27.8	18.1	16.2	.92	Dull, washed..........	Rain..........	Rain.
193	Ohio No. 2..........	No. 5..........	....do..........	....do..........	30.2	25.0	16.6	28.2	.79	Very dirty..........	Clear..........	Clear.
197	....do..........	....do..........	....do..........	....do..........	34.0	23.3	17.4	25.3	.83	Dull, washed..........	....do..........	Do.
203	Ohio No. 3..........	No. 6..........	Shawnee..........	....do..........	36.2	23.8	17.5	22.5	.86	....do..........		

a Lump 60 per cent, small coal 20 per cent, slack 20 per cent.
b Lump 50 per cent, small coal 15 per cent, slack 35 per cent.
c Lump 40 per cent, small coal 20 per cent, slack 40 per cent.
d Small coal 50 per cent, slack 50 per cent.
e Small briquets made by Renfrow machine.
f Large briquets made by English machine.
g Lump 40 per cent, small coal 40 per cent, slack 20 per cent.
h Lump 10 per cent, small coal 45 per cent, slack 45 per cent.
i Small coal 70 per cent, slack 30 per cent.
j Small coal 60 per cent, slack 40 per cent.
k Small coal 65 per cent, slack 35 per cent.
l Small coal 80 per cent, slack 20 per cent.
m Over 2 inches, 25.7 per cent; 1½ to 2 inches, 27.4 per cent; ¾ to 1½ inches, 19.2 per cent.
n Large briquets made by English machine and small briquets made by Renfrow machine.
o Lump 30 per cent, small coal 40 per cent, slack 30 per cent.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation and origin of fuel.			Size of fuel as shipped.	Condition of fuel as fired.						State of weather.	
	Designation of coal.	Designation of bed.	At or near.		Size (per cent).				Average diameter (inches).	Appearance.	Morning.	Afternoon.
					Over 1 inch.	½ to 1 inch.	¼ to ½ inch.	Under ¼ inch.				
1	2	3	4	5	6	7	8	9	10(23)	11	12	13
188	Ohio No. 4	No. 8	Bradley	¾ inch	33.3	23.5	14.4	28.8	.81	Bright	Cloudy	Clear.
201	do	do	do	do	38.5	20.9	13.8	26.8	.86	do	Clear	Do.
202	do	do	do	do	48.2	20.8	12.2	18.8	.99	do	Cloudy	Do.
219	do	do	do	do	30.6	23.6	17.8	28.0	.79	Dull, washed		
220	do	do	do	do	34.4	22.9	15.2	27.5	.83	do		
221	do	do	do	do						Bright, washed	Clear	Clear.
186	Ohio No. 5	do	Rush Run	do	49.2	23.6	11.8	15.4	1.02	Bright	Cloudy	Cloudy.
187	do	do	do	do	44.0	20.2	12.0	23.8	.93	do	Rain	Do.
189	do	do	do	do	28.3	19.7	15.6	36.4	.72	do	Clear	Clear.
190	do	do	do	do	35.1	22.7	15.6	26.6	.83	do		
284	Ohio No. 6	do	Neffs	Run of mine	49.0	14.3	10.9	25.8	.95	do		
253	do	do	do	do	40.0	24.1	13.7	22.2	.90	Dull, washed		
268	Ohio No. 7	No. 7	Danford	Lump	41.1	18.5	14.1	26.3	.88	Bright		
269	do	do	do	do	50.7	19.9	11.5	17.9	1.01	do	Cloudy	Rain.
287	Ohio No. 8	No. 6 Hocking	Dixie	Run of mine	50.2	20.4	11.8	17.6	1.01	do		
246	Ohio No. 9A	No. 4	Clarion	Lump	48.5	17.7	11.2	22.6	.97	Dull		
249	do	do	do	do	58.0	14.5	8.7	18.8	1.06	do	Clear	Clear.
250	do	do	do	do	45.8	17.6	14.1	22.5	.94	do		
252	do	do	do	do	35.4	16.5	16.0	32.1	.80	do		
224	Ohio No. 9B	do	do	Nut and slack	20.6	20.7	16.8	41.9	.63	do		
241	do	do	do	do	28.1	26.9	19.0	26.0	.78	Dull, washed		
243	do	do	do	do	11.7	22.8	23.8	41.7	.55	Washed, dried	Clear	Clear.
244	do	do	do	do	16.6	29.8	22.6	31.0	.66	do		
469	Ohio No. 10	No. 5	Mineral City	Lump	58.3	13.9	9.1	18.7	1.30	Bright	Cloudy	Clear.
474	Ohio No. 11	No. 8	Flushing	do	65.7	16.8	7.6	9.9	1.72		Clear	Do.
475	do	do	do	do	71.7	12.9	6.7	8.7	2.06		do	Cloudy.
483	Ohio No. 12	do	Bellaire	Run of mine	23.8	25.7	20.5	30.0	.72		Light snow	Do.
1	Pennsylvania No. 1	Lower Kittanning	Windber	Lump	(a)					Clean and bright	Cloudy	Do.
2	Pennsylvania No. 2	do	do	do	(a)					do	Clear	Clear.
36	Pennsylvania No. 3		Scranton	Anthracite culm	(b)						do	Do.
74	Pennsylvania No. 4	Pittsburg	Greensburg		(c)					Bright	do	Do.
207	do	do	do	Lump	30.4	21.0	16.9	31.7	.76	do	do	Do.
208	do	do	do	do	25.8	20.3	16.4	37.5	.70	do	do	Do.

209	....do....	....do....	....do....	....do....	30.7	22.7	16.7	29.9	.78	....do....	....do....	Cloudy.
286	Pennsylvania No. 5....	....do....	Ellsworth....	¾ inch....	55.3	14.5	9.8	20.4	1.03	....do....	....do....	Clear.
194	....do....	....do....	....do....	....do....	53.4	22.2	11.8	12.6	1.07	Bright, washed....	....do....	Do.
195	....do....	....do....	....do....	....do....	55.2	18.7	11.8	14.3	1.07	....do....	....do....	Do.
217	Pennsylvania No. 6....	....do....	East Millsboro....	Run of mine....	35.4	21.8	15.0	27.8	.83	Bright, clean....		
218	....do....	....do....	....do....	....do....	26.4	22.5	16.6	34.5	.72	Bright....		
333	....do....	....do....	....do....	....do....	(d)						Partly cloudy.	
198	Pennsylvania No. 7....	....do....	Ligonier....	....do....	13.4	16.7	18.9	51.0	.51	Dull, wet....	Clear....	Cloudy.
307	....do....	....do....	....do....	....do....	16.8	21.7	19.5	42.0	.60	Dull....	Cloudy....	Clear.
199	....do....	....do....	....do....	....do....	19.2	22.0	20.4	38.4	.63	Dull, washed....	Clear....	Do.
236	Pennsylvania No. 8....	Lower Kittanning..	Ehrenfeld....	....do....	6.5	13.6	22.4	57.5	.40	Bright....		
237	....do....	....do....	....do....	....do....	5.8	12.3	19.5	62.4	.38	....do....		
238	....do....	....do....	....do....	....do....	5.4	9.1	14.9	70.6	.34	....do....		
239	....do....	....do....	....do....	....do....	4.4	8.8	16.2	70.6	.33	....do....		
242	....do....	....do....	....do....	....do....	2.0	7.0	14.5	76.5	.28	Bright, dried....		
227	Pennsylvania No. 10...	Pittsburg....	Bruce....	¾ inch....	22.8	22.2	18.5	35.5	.68	Bright, clean....		
228	....do....	....do....	....do....	....do....	23.9	18.7	15.8	41.6	.65	....do....	Cloudy....	
229	....do....	....do....	....do....	....do....	27.4	21.7	16.7	34.2	.73	Bright....		
472	Pennsylvania No. 15...	B, or Miller....	Wehrum....	Run of mine....	8.2	11.1	19.2	61.5	.41		Cloudy....	Cloudy.
473	....do....	....do....	....do....	....do....	4.6	6.9	13.9	74.6	.31		....do....	Clear.
467	....do....	....do....	....do....	....do....	(b)						Clear....	Do.
468	Pennsylvania No. 16...	....do....	Hastings....	....do....	(c)						Light rain....	Light rain.
471	....do....	....do....	....do....	....do....	7.2	11.6	18.8	62.4	.39	Bright....	Clear....	Partly cloudy.
496	Pennsylvania No. 17...	Upper Freeport....	White....	....do....	14.4	28.1	22.3	35.2	.62	....do....	Sleeting....	Light rain.
506	....do....	....do....	....do....	....do....	6.3	15.8	22.1	55.8	.43		Clear....	Clear.
499	Pennsylvania No. 18...	B, or Miller....	Lloydell....	....do....	(b)						Partly cloudy.	Light rain.
515	....do....	....do....	....do....	....do....	(d)						Clear....	Clear.
498	Pennsylvania No. 19...	Pittsburg....	Herminie....	....do....	67.1	12.4	7.8	12.7	1.99		Cloudy....	Light rain.
508	....do....	....do....	....do....	....do....	(d)						Clear....	Clear.
512	Pennsylvania No. 20...	Lower Kittanning..	Seward....	....do....	(d)					Washed....	Partly cloudy.	Do.
514	....do....	....do....	....do....	....do....	(b)						Light snow....	Light rain.
510	Pennsylvania No. 22...	Pittsburg....	Huff....	....do....	(d)						Clear....	Cloudy.
401	Rhode Island No. 1....		Cranston....							Bright gray....	....do....	Partly cloudy.
344	Tennessee No. 1....	Mingo....	Fort Ridge....	Run of mine....	62.7	14.7	8.8	13.8	1.70	Bright....	Cloudy....	Light snow.
345	....do....	....do....	....do....	....do....	57.9	19.1	9.8	13.2	1.71	....do....	....do....	Clear.
346	....do....	....do....	....do....	....do....	71.0	12.4	7.4	9.2	1.44	....do....	Clear....	Cloudy.
411	....do....	....do....	....do....	....do....	(b)					Washed....	....do....	
409	....do....	....do....	....do....	....do....	(d)					....do....	....do....	Clear.
367	Tennessee No. 2....	Log Mountain....	Gatliff....	....do....	43.2	23.9	13.0	19.9	.95	Bright....	....do....	Partly cloudy.
368	....do....	....do....	....do....	....do....	42.8	18.4	12.2	26.6	.90	....do....	....do....	Do.
369	....do....	....do....	....do....	....do....	49.4	22.4	11.8	16.4	1.02	....do....	Cloudy....	Cloudy.
349	Tennessee No. 3....	Regal Block....	....do....	....do....	87.1	5.4	2.7	4.8	2.39	....do....	Clear....	Clear.
350	....do....	....do....	....do....	....do....	79.1	9.1	4.6	7.2	2.18	....do....	....do....	Cloudy.
355	Tennessee No. 4....	Wind Rock....	Oliver Springs....	....do....	20.1	25.2	21.6	33.1	.67	Bright, wet....	Cloudy....	Do.
356	....do....	....do....	....do....	....do....	32.0	19.6	19.0	29.4	1.17	Dull....	....do....	Light snow.
405	....do....	....do....	....do....	....do....	(e)						....do....	Cloudy.
352	Tennessee No. 5....	Brushy Mountain...	Petros....	....do....	27.1	19.3	20.9	32.7	.86	Bright....	....do....	Clear.
357	....do....	....do....	....do....	....do....	12.9	25.8	21.9	39.4	.58	Dull....	Light rain....	Light rain.

[a] Lump 40 per cent, small coal 20 per cent, slack 40 per cent.
[b] Small briquets made by Renfrow machine.
[c] Small coal 40 per cent, slack 60 per cent.
[d] Large briquets made by English machine.
[e] Large briquets made by English machine and small briquets made by Renfrow machine.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation and origin of fuel.			Size of fuel as shipped.	Condition of fuel as fired.						State of weather.	
	Designation of coal.	Designation of bed.	At or near.		Size (per cent).				Average diameter (inches).	Appearance.	Morning.	Afternoon.
					Over 1 inch.	½ to 1 inch.	¼ to ½ inch.	Under ¼ inch.				
1	2	3	4	5	6	7	8	9	10(23)	11	12	13
358	Tennessee No. 5	Brushy Mountain	Petros	Run of mine	19.9	28.5	20.6	31.3	.69	Dull	Partly cloudy	Clear.
379	Tennessee No. 6	Lower Sewanee	Waldensia	do	27.7	27.8	19.8	24.7	.79	Bright	Clear	Partly cloudy.
381	do	do	do	do	21.7	17.4	19.6	41.3	.63	Dull	do	Clear.
372	Tennessee No. 7A	Wilder	Wilder	Screenings	51.6	22.0	12.4	13.4	1.05	Bright	Cloudy	Do.
373	do	do	do	do	26.1	37.5	18.5	17.9	.83	do	do	Do.
374	do	do	do	do	47.3	20.4	12.6	19.7	.98	do	Partly cloudy	Do.
406	Tennessee No. 7B	do	do	Slack	(a)					Washed	Clear	Cloudy.
384	Tennessee Nos. 8A and 8B.	First above Sewanee	Clifty	Run of mine	36.6	28.1	15.8	19.5	.90		do	Clear.
385	do	do	do	do	37.0	26.1	14.6	22.3	.88		Partly cloudy	Light rain.
388	do	do	do	do	27.5	25.6	19.4	27.5	.77	Washed	Cloudy	Cloudy.
363	Tennessee No. 9A	Sewanee	Coalmont	Lump	12.6	24.5	24.5	38.4	.57	Bright	Light rain	Do.
364	do	do	do	do	13.8	22.4	23.8	40.0	.57	Dull	Cloudy	Do.
365	do	do	do	do	7.1	17.3	22.8	52.8	.44	Bright	Clear	Clear.
393	Tennessee No. 9B	do	do	Slack	(a)					Washed	Partly cloudy	Partly cloudy.
407	Tennessee No. 10	Battle Creek	Orme	do	(a)					do	Light rain	
408	do	do	do	do	(b)					do		Clear.
22	Texas No. 1		Wootlers Station	Screenings	(a)						Clear	Do.
291	Texas No. 4		Hoyt	Run of mine							Cloudy	Cloudy.
298	do		do	do	44.2	21.7	14.0	20.1	.95			
303	do		do	do	14.7	15.2	14.7	55.4	.58		Clear	
402	Utah No. 2	Coalville	Coalville	Slack	(a)						do	
403	do	do	do	do	(b)							Partly cloudy.
404	do	do	do	do	(b)						Clear	Cloudy.
281	Virginia No. 1	Wilson	Crab Orchard	Run of mine	30.0	21.3	17.5	31.2	.76	Bright		
282	do	do	do	do	25.4	21.6	19.4	33.6	.70	do		
247	Virginia No. 2	McConnell	do	do	49.6	23.0	12.4	15.0	1.02	do	Clear	Clear.
251	do	do	do	do	45.0	18.0	13.4	23.6	.93	do	do	Rain; cloudy.
256	do	do	do	do	28.9	18.9	15.0	37.2	.72	Dull	do	Clear.
260	do	do	do	do	49.5	23.3	12.6	14.6	1.03	Washed	do	Do.
280	Virginia No. 3	Upper Banner	Toms Creek	Lump	44.7	20.2	15.7	19.4	.94		Cloudy	Rain.
283	do	do	do	do	32.8	16.5	15.6	35.1	.76		Clear	Clear.
240	Virginia No. 4	Darby	Darby	do	46.5	21.9	12.9	18.7	.98	Bright		

248	do	do	do	do	46.1	20.4	12.5	21.0	.96	do	Clear	Do.
254	do	do	do	do	63.6	15.4	7.9	14.1	1.13	do	Cloudy	Cloudy.
476	Virginia No. 5A	Big Seam	Blacksburg	Pea	4.0	31.1	37.7	27.2	.53	Dull	Light rain	Light rain.
483	do	do	do	do	2.1	23.0	36.4	38.5	.45		Cloudy	Cloudy.
494	Virginia No. 5B	do	do	Slack	(c)						do	Do.
507	Virginia No. 6	No. 4	Richlands	Run of mine	13.5	9.0	16.3	61.2	.46		Clear	Clear.
260	Washington No. 1B		Renton	do	38.9	23.9	14.5	22.7	1.28	Dull		
359	Washington No. 2		Roslyn	Lump	20.9	21.3	18.0	39.8	.64	Bright	Clear	Do.
360	do		do	do	41.4	22.3	15.3	21.0	.93	do	do	Do.
361	do		do	do	33.5	22.8	15.8	27.9	.81	do	Partly cloudy	Do.
412	do		do	do	(c)						Cloudy	Do.
24	West Virginia No. 1	Pittsburg	Kingmont	Run of mine	(d)					Clean and bright	Rain	Do.
26	West Virginia No. 2	do	Clarksburg	do	(e)					do	Cloudy	Do.
28	West Virginia No. 3	Upper Freeport	Morgantown	do	(f)					do	Clear	Cloudy.
31	West Virginia No. 4	do	Bretz	do	(g)					Bright	do	Clear.
34	West Virginia No. 5	do	Coalton	Screenings	(f)					Clean and bright	Rainy	Cloudy.
39	West Virginia No. 6	Fire Creek	Rush Run	Run of mine	(h)					Bright	Clear	Clear.
43	do	do	do	do	(h)					do	do	Do.
51	West Virginia No. 7	Sewell	Sun	do	(h)					do	Cloudy	Cloudy.
53	West Virginia No. 8	Ansted	Ansted	do	(f)					do	do	Do.
60	West Virginia No. 9	Powellton	Powellton	do	(d)					do	Clear	Clear.
54	West Virginia No. 10	No 6	Mora	Screenings	(i)					do	do	Do.
56	West Virginia No. 11	No. 3	Zenith	Run of mine	(j)					do	do	Do.
46	West Virginia No. 12	No 8	Big Sandy	do	(h)					do	Cloudy	Cloudy.
59	do	do	do	do	(b)						do	Do.
179	West Virginia No. 13	Ansted	Page	do	15.4	19.7	22.4	42.5	.57	Bright, clean	Clear	Clear.
180	do	do	do	do	12.7	13.3	19.6	54.4	.48	do	do	Do.
178	West Virginia No. 14	Eagle	do	do	26.8	14.5	16.7	42.0	.67	Bright	do	Do.
181	do	do	do	do	23.1	15.5	16.4	45.0	63	Bright, clean	Cloudy	Do.
214	West Virginia No. 15	Pittsburg	Clarksburg	do	33.1	24.4	15.0	27.5	.82	do		
215	do	do	do	do	32.6	24.2	15.8	27.4	.82	do		
216	do	do	do	do	43.5	20.3	14.5	21.7	.93	do		
304	West Virginia No. 16A	do	Monongah	¾ inch lump	50.6	22.8	10.1	16.5	1.03	do	Clear	
306	do	do	do	do	33.9	19.6	19.0	27.5	.82	Bright	do	
225	West Virginia No. 17	Bakerstown	Bretz	Run of mine	11.0	11.0	16.2	61.8	.43	Dull		
226	do	do	do	do	16.5	14.0	15.3	54.2	.52	do		
230	do	do	do	do	29.6	20.2	15.7	34.5	.75	Dull, washed		
261	West Virginia No. 18	Local Glen Alum	Glen Alum	do	22.4	20.0	17.1	40.5	.65	Bright	Clear	Clear.
262	do	do	do	do	47.7	17.2	11.9	23.2	.95			
285	West Virginia No. 19	Sewell	McDonald	do	14.8	11.6	15.3	58.3	.48	Dull		
289	do	do	do	do	13.4	11.7	16.2	58.7	.48		Snow	Hazy.
231	do	do	do	do	(a)						Clear	
272	West Virginia No. 20	Keystone	Acme	do	31.1	22.3	19.4	27.2	.79	Bright		
273	do	do	do	do	37.7	20.0	18.5	33.8	.73	do		
264	do	do	do	do	23.0	23.7	25.4	27.9	.71	Washed	Clear	Clear.
266	do	do	do	do	30.9	24.4	21.2	23.5	.81	do		
274	West Virginia No 21	Winifrede	Winifrede	do	60.3	15.7	10.8	7.2	1.19		Rain	Rain.

a Large briquets made by —
b Small briquets made by
c Large briquets made by and small briquets made by Renfrow machine.
d Small coal 60 per cent, sl
e Lump 20 per cent, small ack 40 per cent.

f Small coal 50 per cent, slack 50 per cent.
g Small coal 70 per cent, slack 30 per cent.
h Small coal 40 per cent, slack 60 per cent.
i Small coal 30 per cent, slack 70 per cent.
j Small coal 20 per cent, slack 80 per cent.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo. and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation and origin of fuel.			Size of fuel as shipped.	Condition of fuel as fired.						State of weather.	
	Designation of coal.	Designation of bed.	At or near.		Size (per cent). Over 1 inch.	$\frac{1}{2}$ to 1 inch.	$\frac{1}{4}$ to $\frac{1}{2}$ inch.	Under $\frac{1}{4}$ inch.	Average diameter (inches).	Appearance.	Morning.	Afternoon.
1	2	3	4	5	6	7	8	9	10(23)	11	12	13
275	West Virginia No. 21	Winifrede	Winifrede	Run of mine	44.0	15.3	11.5	29.2	0.89		Clear	Clear.
296	do	do	do	do	40.0	20.0	14.7	25.3	.88	Bright	do	Do.
267	do	do	do	do	36.2	26.6	17.7	19.5	.89	Bright, washed		
446	West Virginia No. 22A		Hernshaw	Screenings	9.7	17.8	21.5	51.0	.48		Clear	Cloudy.
447	do		do	do	5.6	15.8	20.8	57.8	.41		do	Clear.
454	do		do	do	15.2	26.8	21.7	36.3	.61	Washed	Cloudy	Do.
438	West Virginia No. 22B		do	Run of mine	53.6	20.0	10.0	16.4	1.27		Clear	Partly cloudy.
439	WestVirginia No. 23A	Cedar Grove	Monarch	do	56.3	21.9	12.0	9.8	1.31	Bright	Cloudy	Do.
440	do	do	do	do	32.9	20.0	15.4	31.7	.87	do	do	Cloudy.
444	West Virginia No. 23B	do	do	Slack	12.1	23.2	24.6	40.1	.56	Washed	do	Do.
445	do	do	do	do	25.2	21.6	16.6	36.6	.70	Dull	do	Partly cloudy.
63	Wyoming No. 1	No. 4	Sheridan	Lump	(a)					Bright	Clear	Clear.
61	Wyoming No. 2		Cambria	Run of mine, crushed.	(b)					Very dirty	do	Do.
196	Wyoming No. 2B		do	Run of mine	54.3	18.4	14.5	12.8	1.06	Dull	do	Do.
210	do		do	do	34.8	21.5	20.4	23.3	.84	Dull, dirty	Rain	Do.
213	do		do	do	40.4	26.7	15.2	17.7	1.14	do	Clear	Do.
211	Wyoming No. 3		Aladdin		58.7	17.3	11.6	12.4	1.40	Dull		
212	do		do		51.0	20.6	12.6	15.8	1.28	Dull, dirty	Clear	Clear.
223	do		do		27.9	21.3	20.5	30.3	.74	Dull, washed		
399	Wyoming No. 4		Hanna	Run of mine	23.1	18.3	19.2	39.4	.66	Bright	Clear	Clear.
400	Wyoming No. 6		Kemmerer	do	13.3	25.5	25.4	35.8	.59		do	Do.
419	do		do	do	(c)						do	Partly cloudy.
	MISCELLANEOUS.											
451	Argentina No. 1		Province of Mendoza.		20.5	18.8	18.7	42.0	.63		Cloudy	Clear.
458	do		do		4.1	10.9	13.6	71.4	.32	Washed	Light snow	Cloudy.
485	do		do		(d)					do	Light rain	
172	Brazil No. 1		Rio Grande do Sul	Run of mine	91.1	3.6	3.1	2.2	1.42	Dull	Clear	
173	do		do	do	75.7	9.2	6.4	8.7	1.26	do		

	Mixed coals (accurately sized):											
346	1½ to 3 inches				100.0	.0	.0	.0	2.25	Dull, wet	Clear	Clear.
347	1 to 1½ inches				100.0	.0	.0	.0	1.25	...do	Light snow	Cloudy.
351	¾ to 1 inch				.0	100.0	.0	.0	.88	Dull, gray	Cloudy	Light snow.
362	½ to ¾ inch				.0	100.0	.0	.0	.63	Dull	Clear	
366	⅜ to ½ inch				.0	.0	100.0	.0	.44	...do	...do	
370	¼ to ⅜ inch				.0	.0	100.0	.0	.31	Dull, dirty	...do	
371	Under ¼ inch				.0	.0	.0	100.0		Dull		Clear.
	Mixed coals:											
245	Pa. No. 8 dried and Va. No. 4.				44.8	13.6	9.3	32.3	.38	Dried	...do	Do.
414	Utah No. 1 and R. I. No. 1.				(d)						...do	
415	...do				(c)							Clear.
416	Utah No. 2 and R. I. No. 1.				(d)						Clear	Cloudy.
	Special tests:											
500	Illinois	No. 6	Collinsville	Nut							Partly cloudy	Do.
501	...do	...do	...do	...do							Light rain	Do.
502	...do	...do	...do	...do							...do	Do.
503	...do	...do	...do	...do							...do	Clear.
504	...do	...do	...do	...do							Light snow	Light snow.
505	...do	...do	...do	...do							Cloudy	Clear.
517	...do	...do	...do	...do							...do	Partly cloudy.
479	Washery refuse				5.6	13.8	16.0	64.0	.38		Clear	Clear.
519	Mixed coke										Cloudy	Do.

a Small

b Small

c Large

d Small ... and small briquets made by Renfrow machine.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Boiler No.	Kind of grate or stoker.	Trial. Date.	Trial. Duration (hours).	Grate surface (square feet).	Kind of draft.	Average pressure. Barometer (inches of mercury).	Average pressure. Steam gage (pounds per square inch).	Average pressure. Force of draft (inches of water). Hood.	Average pressure. Force of draft (inches of water). Furnace.	Average pressure. Under fire.	Average temperatures (°F.). External air.	Average temperatures (°F.). Fire room.	Average temperatures (°F.). Steam.	Average temperatures (°F.). Feed water. In tank.	Average temperatures (°F.). Feed water. Entering boiler.	Average temperatures (°F.). Escaping gases.	Average temperatures (°F.). Furnace.
1	2	14	15	16 (1)	17 (2)	18 (3)	19 (6.4)	20 (11)	21 (11.1)	22 (12)	23 (13)	24 (14)	25 (15)	26 (16)	27 (17)	28 (18)	29 (20)	30 (21)	31 (22.1)
17	Ala. No. 1	1	Plain	9,30,04	10.03	40.55	Natural	29.70	85.1	0.36	0.18	0.0	76.5	82.5	327.3	77.2	153.0	643	......
21	do	2	do	10,6,04	8.25	40.55	do	29.86	88.0	.46	.18	.0	60.0	65.4	329.5	71.0	167.0	548	......
16	Ala. No. 2	1	do	9,29,04	10.02	40.55	do	29.67	86.6	.39	.17	.0	86.0	89.0	328.4	76.0	178.0	644	......
382	Ala. No. 2B	1	do	5,8,06	10.00	40.55	do	29.60	80.0	.69	.14	......	61.0	64.0	323.5	64.5	190.0	529	2,280
383	do	1	do	5,9,06	10.03	40.55	do	29.74	73.0	.64	.12	......	61.0	62.0	318.1	63.0	178.0	461	2,020
410	do	1	do	7,18,06	9.98	40.55	do	29.42	84.0	.61	.15	......	87.0	95.0	326.6	80.0	186.0	639	2,215
390	Ala. No. 3	1	do	6,8,06	10.00	40.55	do	29.20	81.5	.55	.18	......	82.0	84.0	324.6	75.5	195.0	665	2,040
394	do	1	do	6,13,06	10.00	40.55	do	29.36	82.0	.60	.21	......	73.0	75.0	325.0	74.0	202.0	655	2,160
375	Ala. No. 4	1	do	4,26,06	10.17	40.55	do	29.14	77.5	.64	.20	......	79.0	84.0	321.6	60.5	167.0	608	2,461
376	do	1	do	4,27,06	9.77	40.55	do	29.19	76.0	.55	.19	......	79.0	80.0	320.4	63.0	191.0	550	......
377	do	1	do	4,28,06	10.00	40.55	do	29.20	76.0	.63	.22	......	80.0	81.0	320.4	63.5	187.0	568	......
378	do	1	do	5,3,06	8.03	40.55	do	29.16	78.5	.60	.18	......	78.0	81.0	322.4	66.0	197.0	496	......
413	do	1	do	7,23,06	9.87	40.55	do	29.34	81.5	.66	.10	......	82.0	96.0	324.8	82.0	180.0	763	2,430
478	Ala. No. 5	4	do	12,17,06	9.93	40.55	do	29.70	75.5	.89	.19	......	35.0	57.0	320.2	44.0	179.0	651	2,561
480	do	4	do	12,19,06	9.57	40.55	Forced	29.65	70.0	.86	.09	+ .25	31.0	45.0	315.8	43.0	160.0	640	......
484	Ala. No. 6	4	do	12,31,06	9.58	40.55	Natural	29.37	71.0	.82	.17	......	42.0	58.0	316.6	38.0	160.0	680	......
9	Ark. No. 1	2	do	9,21,04	10.07	40.55	do	29.94	93.1	.36	.12	.00	61.2	70.8	332.6	73.2	186.0	601	......
14	do	1	do	9,27,04	10.03	40.55	do	29.45	90.3	.35	.15	.00	83.2	86.6	320.9	73.8	180.0	624	......
8	Ark. No. 2	2	do	9,17,04	10.07	40.55	do	29.51	89.8	.35	.15	.00	82.8	86.6	330.6	72.4	188.5	571	......
11	do	1	do	9,23,04	9.98	40.55	do	29.69	91.7	.37	.15	.00	77.3	81.3	332.0	71.6	184.5	608	......
29	Ark. No. 3	2	do	10,15,04	10.02	40.55	do	29.70	85.0	.40	.16	.00	65.0	70.6	327.3	67.0	156.0	582	......
35	do	1	do	10,22,04	10.08	40.55	do	29.51	81.0	.60	.22	.00	54.6	61.3	324.3	61.0	144.0	597	......
40	Ark. No. 4	1	do	10,28,04	9.95	40.55	do	29.62	85.6	.45	.19	.00	59.2	65.0	327.7	57.8	189.0	560	......
42	do	2	do	10,31,04	7.03	40.55	do	29.77	82.3	.54	.26	.00	60.0	64.0	325.3	56.5	165.0	498	......
41	Ark. No. 5	1	do	10,29,04	10.13	40.55	do	29.70	82.2	.53	.28	.00	61.0	66.0	325.2	57.3	190.0	538	......
293	Ark. No. 7A	1	do	1,15,06	9.80	40.55	do	28.99	66.5	.62	.15	......	51.0	63.0	312.3	42.0	133.0	523	1,972
294	do	1	do	1,16,06	10.00	40.55	Forced	29.46	66.0	.62	......	+ .25	39.0	62.0	312.3	42.0	120.0	560	2,060
297	Ark. No. 8	1	do	1,19,06	9.72	40.55	do	29.21	73.0	.63	.03	......	44.0	59.0	318.1	42.0	111.0	588	1,964
308	do	1	do	1,31,06	5.03	40.55	Natural	29.71	67.5	.72	......	......	31.0	51.0	313.5	39.0	114.0	567	1,961
309	do	1	do	1,31,06	5.03	40.55	Forced	29.46	73.0	.62	......	......	40.0	61.0	318.1	39.0	112.0	609	2,403

340	Ark. No. 10	2	Rocking	3,5,06	9.00	36.40	do	29.78	78.5	.82	.12	......	83.0	44.0	322.4	42.0	181.0	629	......
75	Colo. No. 1	2	Plain	12,8,04	9.97	40.55	Natural	29.38	79.2	.66	.83	.00	47.8	64.4	322.8	45.5	168	549	......
386	Fla. No. 1	1	do	5,28,06	4.07	40.55	do	29.39	75.0	.69	.13	......	56.0	61.0	319.7	73.0	173	685	2,457
481	Ga. No. 1	4	do	12,20,06	9.47	40.55	do	29.29	78.5	.81	.19	......	36.0	47.0	322.5	42.0	164	649	......
18	Ill. No. 1	2	do	10,3,04	9.93	40.55	do	29.56	83.7	.40	.18	.00	70.3	74.2	326.3	74.4	185	564	......
19	Ill. No. 2	2	do	10,4,04	9.97	40.55	do	29.48	86.6	.42	.15	.00	73.1	77.7	328.3	74.3	178	554	......
38	Ill. No. 3	1	do	10,26,04	10.13	40.55	do	29.66	84.4	.58	.21	.00	56.3	61.7	326.9	58.6	181	637	......
48	Ill. No. 4	1	do	11,7,04	10.07	40.55	do	29.45	87.7	.55	.16	.00	60.0	66.0	329.2	60.0	......	618	......
50	do	2	do	11,9,04	10.02	40.55	do	29.82	83.0	.52	.21	.00	41.5	52.0	325.6	57.0	186	570	......
73	Ill. No. 6	2	do	12,6,04	9.92	40.55	do	29.62	97.2	.69	.23	.00	38.0	53.3	335.7	44.1	182	624	......
106	Ill. No. 6B	1	do	5,23,05	10.00	40.55	do	29.58	75.0	.55	.25	......	70.0	80.0	319.6	62.0	184	699	2,213
313	do	1	do	2,3,06	5.52	40.55	do	29.45	72.0	.64	.17	......	44.0	59.0	317.3	40.0	124	495	......
314	do	1	do	2,5,06	4.13	40.55	Natural, forced	29.87	68.0	.79	.07	......	12.0	42.0	314.0	38.0	110	607	2,359
122	Ill. No. 7C	2	Rocking	6,16,05	10.07	36.40	do	29.37	72.0	.58	.30	......	87.0	90.0	317.2	73.0	170	429	......
129	do	1	Plain	7,1,05	8.35	40.55	do	29.38	73.0	.55	.24	......	81.0	92.0	318.0	71.0	156	592	......
142	Ill. No. 7D	1	do	7,18,05	10.02	40.55	do	29.58	81.0	.60	.16	......	91.0	95.0	324.2	75.0	196	582	......
143	do	1	do	7,19,05	10.00	40.55	do	29.58	79.0	.58	.18	......	89.0	92.0	322.7	75.0	187	524	......
146	do	2	Rocking	7,22,05	10.07	36.40	do	29.46	67.0	.61	.22	......	81.0	87.0	313.1	74.0	181	500	......
516	Ill. No. 7E	4	Plain	2,26,07	7.85	40.55	Forced	29.39	79.0	.87	.13	+ .31	40.0	57.0	322.9	40.0	......	742	......
101	Ill. No. 8	2	Rocking	5,15,05	10.08	36.40	Natural	29.30	83.5	.63	.32	......	74.0	85.0	326.0	61.5	179	584	......
102	do	1	Plain	5,17,05	10.00	40.55	do	......	78.0	.63	.25	......	58.0	68.0	322.0	60.0	177	702	......
103	Ill. No. 9A	1	do	5,19,05	10.02	40.55	do	29.56	81.0	.56	.27	......	67.0	77.0	324.2	61.0	181	634	2,218
104	do	1	do	5,20,05	9.90	40.55	do	29.56	80.0	.37	.19	......	69.0	81.0	323.5	63.0	192	600	2,155
105	do	1	do	5,22,05	10.08	40.55	do	29.41	78.0	.66	.25	......	71.0	80.0	321.9	60.5	178	732	2,220
113	do	2	Rocking	5,31,05	9.98	36.40	do	29.65	75.0	.50	.20	......	73.0	81.0	319.6	65.0	178	587	......
121	Ill. No. 9B	2	do	6,15,05	9.93	36.40	do	29.43	75.0	.59	.19	......	87.0	90.0	319.5	73.0	169	494	......
492	Ill. No. 9C	4	Plain	1,10,07	10.00	40.55	Forced	29.34	76.5	.91	.05	+ .16	41.0	66.0	321.0	42.0	162	670	......
107	Ill. No. 10	1	do	5,24,05	10.17	40.55	Natural	29.46	76.0	.59	.32	......	75.0	84.0	320.4	63.0	174	696	2,229
108	do	1	do	5,25,05	10.00	40.55	do	29.30	76.0	.42	.21	......	70.0	83.0	320.3	62.0	160	657	......
109	do	2	Rocking	5,26,05	9.98	36.40	do	29.57	78.0	.51	.29	......	66.0	75.0	322.0	62.5	165	479	......
110	do	2	do	5,27,05	9.95	36.40	do	29.52	75.0	.45	.26	......	68.0	79.0	319.6	62.0	184	415	......
114	do	2	do	6,1,05	10.05	36.40	do	29.57	75.0	.51	.21	......	75.0	84.0	319.6	65.0	180	593	......
137	Ill. No. 11A	2	do	7,12,05	10.03	36.40	do	29.40	74.0	.60	.16	......	76.0	79.0	318.9	73.0	189	518	......
138	do	2	do	7,13,05	10.03	36.40	do	29.55	74.0	.60	.18	......	83.0	87.0	318.9	72.0	181	538	2,376
139	do	2	do	7,14,05	9.93	36.40	do	29.63	77.0	.62	.18	......	87.0	89.0	321.2	73.0	182	483	2,435
141	do	1	Plain	7,17,05	7.08	40.55	do	29.55	79.0	.60	.15	......	91.0	94.0	322.7	73.0	174	556	......
111	Ill. No. 11B	2	Rocking	5,29,05	10.08	36.40	do	29.39	73.3	.55	.28	......	87.0	95.0	318.4	63.0	182	537	......
112	do	2	do	5,30,05	10.07	36.40	do	29.51	80.0	.48	.27	......	74.0	85.0	323.5	66.0	178	535	......
115	do	1	Plain	6,2,05	9.87	40.55	do	29.53	76.0	.61	.26	......	79.0	87.0	320.4	65.0	165	552	......
116	do	1	do	6,3,05	6.05	40.55	do	29.61	76.0	.49	.22	......	80.0	88.0	320.4	64.0	169	544	......
117	do	1	do	6,5,05	10.10	40.55	do	29.38	75.0	.50	.20	......	89.0	95.0	319.5	66.0	172	589	......
118	do	1	do	6,6,05	9.90	40.55	do	29.33	77.0	.39	.16	......	88.0	95.0	321.1	68.5	171	557	......
119	do	1	do	6,7,05	10.07	40.55	do	29.49	75.5	.57	.25	......	81.0	88.0	320.0	66.0	167	609	......
120	Ill. No. 11C	2	Rocking	6,14,05	9.95	36.40	do	29.45	72.0	.58	.23	......	86.0	93.0	317.1	68.0	166	491	......
312	do	1	Plain	2,3,06	3.62	40.55	do	29.45	71.0	.59	.11	......	30.0	51.0	316.4	40.0	111	517	2,400
127	Ill. No. 12	1	do	6,29,05	10.03	40.55	do	29.47	73.0	.59	.19	......	75.0	84.0	318.1	74.0	162	617	......
128	do	1	do	6,30,05	10.05	40.55	do	29.41	75.0	.46	.19	......	82.0	91.0	319.6	72.0	159	581	......
131	do	2	Rocking	7,5,05	10.00	36.40	do	29.34	74.0	.57	.19	......	82.0	87.0	318.9	74.0	167	584	......
133	do	2	do	7,7,05	10.03	36.40	do	29.35	81.0	.65	.22	......	80.0	88.0	324.2	74.0	185	519	......
135	do	2	do	7,10,05	10.03	36.40	do	29.35	74.0	.63	.18	......	73.0	77.0	318.9	71.0	180	557	......
136	do	2	do	7,11,05	9.68	36.40	do	29.30	75.0	.67	.21	......	73.0	78.0	319.6	73.0	177	524	......
463	Ill. No. 12B	4	Plain	11,27,06	10.03	40.55	do	29.89	81.0	.81	.11	......	41.0	51.0	324.4	45.0	152	638	2,490

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Boiler No.	Kind of grate or stoker.	Trial.		Grate surface (square feet).	Kind of draft.	Average pressure.				Average temperatures (°F.).							
				Date.	Duration (hours).			Barometer (inches of mercury).	Steam gage (pounds per square inch).	Force of draft (inches of water).		Under fire.	External air.	Fire room.	Steam.	Feed water.		Escaping gases.	Furnace.
										Hood.	Furnace.					In tank.	Entering boiler.		
1	2	14	15	16 (1)	17 (2)	18 (3)	19 (6.4)	20 (11)	21 (11.1)	22 (12)	23 (13)	24 (14)	25 (15)	26 (16)	27 (17)	28 (18)	29 (20)	30 (21)	31 (22.1)
132	Ill. No. 13	2	Rocking	7,6,05	9.98	36.40	Natural	29.36	76.0	.48	.13	......	76.0	87.0	320.4	73.0	188	531	......
134	do	2	do	7,8,05	10.02	36.40	do	29.40	78.0	.65	.18	......	79.0	86.0	322.0	73.0	171	516	......
144	do	1	Plain	7,20,05	8.95	40.55	do	29.53	79.0	.45	.10	......	78.0	83.0	722.7	75.0	176	553	......
145	do	2	Rocking	7,21,05	7.63	36.40	do	29.46	75.0	.46	.13	......	77.0	83.0	319.6	75.0	197	480	......
123	Ill. No. 14	2	do	6,22,05	9.95	36.40	do	29.43	73.0	.60	.28	......	80.0	83.0	318.0	75.0	178	501	......
125	do	1	Plain	6,24,05	9.87	40.55	do	29.61	74.0	.57	.20	......	81.0	89.0	318.9	73.0	163	570	......
130	do	1	do	7,3,05	9.92	40.55	do	29.21	77.0	.52	.14	......	82.0	87.0	321.2	72.0	154	582	......
126	Ill. No. 15	1	do	6,28,05	9.88	40.55	do	29.50	69.0	.55	.18	......	76.0	82.0	314.8	72.0	159	571	......
152	do	1	do	7,29,05	10.03	40.55	do	29.43	75.0	.46	.13	......	82.0	86.0	319.7	74.0	193	563	2,439
150	Ill. No. 16	1	do	7,27,05	7.53	40.55	do	29.46	74.0	.48	.11	......	76.0	82.0	318.9	74.5	190	585	......
140	Ill. No. 18	2	Rocking	7,15,05	10.00	36.40	do	29.67	75.0	.63	.18	......	89.0	91.0	319.6	73.0	182	495	......
148	do	1	Plain	7,25,05	10.00	40.55	do	29.68	73.0	.53	.19	......	77.0	83.0	318.1	74.0	183	562	......
147	do	2	Rocking	7,24,05	9.95	36.40	do	29.63	72.0	.57	.17	......	77.0	82.0	317.2	77.0	192	561	......
149	do	1	Plain	7,26,05	5.32	40.55	do	29.66	74.0	.56	.14	......	77.0	82.0	318.9	73.0	191	559	2,060
160	Ill. No. 19A	1	do	8,8,05	10.02	40.55	do	29.51	77.0	.40	.14	......	82.0	90.0	321.2	74.0	195	580	2,428
161	do	1	do	8,9,05	9.97	40.55	do	29.46	77.0	.54	.20	......	86.0	93.0	321.2	73.0	194	516	2,080
163	do	1	do	8,11,05	9.98	40.55	do	29.53	78.0	.67	.17	......	85.0	92.0	322.0	74.0	196	608	2,227
170	do	2	Rocking	8,21,05	9.07	36.40	do	29.50	79.0	.56	.16	......	87.0	91.0	322.8	79.0	198	595	2,039
171	do	2	do	8,22,05	9.97	36.40	do	29.52	77.0	.49	.17	......	74.0	81.0	321.2	79.0	199	541	......
175	Ill. No. 19B	1	Plain	8,26,05	9.90	40.55	do	29.68	74.0	.41	.09	......	76.0	87.0	318.9	77.5	195	591	2,470
204	do	2	Rocking	10,2,05	10.03	36.40	do	29.66	72.5	.41	.11	......	66.0	73.0	317.7	72.5	194	589	2,447
205	do	2	do	10,3,05	9.93	36.40	do	29.60	71.0	.40	.12	......	61.0	69.0	316.4	72.0	189	598	2,448
420	Ill. No. 19C	2	Plain	8,14,06	10.03	40.55	do	29.32	79.5	.65	.12	......	86.0	91.0	323.3	80.0	155	585	......
423	do	2	do	8,17,06	10.03	40.55	do	29.33	78.5	.59	.14	......	87.0	93.0	322.5	81.0	163	571	......
424	Ill. No. 19D	2	do	8,23,06	10.00	40.55	do	29.27	83.5	.64	.12	......	87.0	91.0	326.2	82.0	168	599	......
425	do	2	do	8,24,06	10.00	40.55	do	29.29	81.0	.65	.14	......	87.0	92.0	324.4	82.0	168	601	......
421	Ill. No. 19E	2	do	8,15,06	10.00	40.55	do	29.26	82.0	.66	.11	......	83.0	87.0	325.2	80.0	164	578	......
422	do	2	do	8,16,06	10.07	40.55	do	29.29	78.5	.62	.12	......	87.0	92.0	322.5	80.0	161	590	......
292	Ill. No. 20	1	do	1,14,06	9.80	40.55	do	29.18	70.5	.53	.10	......	44.0	59.0	316.0	42.0	138	556	2,020

301	do.	2	Rocking	1,24,06	9.05	36.40	do.	29.93	69.0	.57	.30		34.0	50.0	314.8	42.0	170	648	
302	do.	2	do.	1,25,06	9.02	36.40	do.	29.93	76.0	.53	.70		38.0	59.0	320.4	40.0	177	681	2,708
315	Ill. No. 21	1	Plain	2,5,06	4.88	40.55	do.	29.87	74.5	.63	.16		18.0	48.0	319.3	38.0	118	570	2,499
316	do.	1	do.	2,6,06	10.03	40.55	do.	29.94	69.0	.59	.15		17.0	41.0	314.8	38.0	113	550	2,401
318	do.	1	do.	2,8,06	7.30	40.55	Forced	29.57	69.5	.76	.04		34.0	56.0	315.2	38.0	112	605	2,508
324	Ill. No. 22A	1	do.	2,14,06	9.93	40.55	Natural	29.80	71.5	.59	.20		28.0	52.0	316.8	37.5	105	560	2,850
325	do.	1	do.	2,15,06	10.00	40.55	do.	29.84	72.0	.54	.18		24.0	48.0	317.3	37.0	119	565	2,828
328	do.	1	do.	2,19,06	9.90	40.55	do.	29.45	71.0	.78	.14		53.0	62.0	316.4	38.0	133	613	2,829
306	Ill. No. 23A	1	do.	1,29,06	9.40	40.55	do.	29.46	67.0	.46	.13		47.0	66.0	313.1	39.0	125	551	2,402
317	do.	1	do.	2,7,06	8.12	40.55	do.	29.76	70.5	.55	.13		14.0	45.0	316.0	38.0	121	550	2,397
321	Ill. No. 23B	1	do.	2,12,06	4.46	40.55	do.	29.71	70.0	.75	.27		40.0	57.0	315.6	38.0	100	568	
322	do.	1	do.	2,12,06	3.65	40.55	Forced	29.65	74.5	.65	.16		52.0	60.0	319.3	38.0	100	605	
335	Ill. No. 24B	1	do.	2,24,06	9.62	40.55	Natural	29.24	74.5	.55	.22		56.0	61.0	319.3	43.0	177	617	2,708
336	do.	1	do.	2,26,06	6.05	40.55	do.	29.45	73.5	.63	.26		33.0	56.0	318.5	43.0	164	603	
337	do.	1	do.	2,26,06	3.88	40.55	do.	29.45	72.0	.61	.20		30.0	52.0	317.3	43.0	156	662	
338	Ill. Nos. 25A and 25B.	1	do.	2,28,06	9.67	40.55	do.	29.51	71.5	.75	.21		32.0	49.0	316.8	42.0	165	642	
339	do.	1	do.	3,1,06	10.00	40.55	do.	29.11	73.0	.74	.21		49.0	58.0	318.1	42.0	163	669	
341	Ill. No. 26	2	Rocking	3,6,06	10.00	36.40	do.	29.72	76.0	.65	.34		39.0	51.0	320.4	46.0	188	534	
342	do.	2	do.	3,7,06	8.87	36.40	do.	29.53	77.0	.64	.30		42.0	53.0	321.2	41.0	189	536	2,264
353	Ill. No. 27	1	Plain	3,26,06	10.00	40.55	do.	29.13	78.0	.60	.18		59.0	66.0	322.0	40.0	172	524	2,360
354	do.	1	do.	3,27,06	10.02	40.55	do.	29.47	76.0	.72	.17		45.0	60.0	320.4	39.0	168	508	2,162
459	Ill. No. 28A	4	do.	11,22,06	9.95	40.55	do.	29.70	80.0	.80	.15		38.0	57.0	323.7	47.0	171	614	2,601
457	Ill. No. 28B	4	do.	11,13,06	9.13	40.55	do.	29.40	81.0	.81	.16		39.0	56.0	324.4	53.0	153	659	2,606
448	Ill. No. 28C	4	do.	10,26,06	10.03	40.55	do.	29.16	79.0	.76	.17		73.0	81.0	322.9	62.0	170	671	2,862
452	do.	4	do.	11,6,06	10.00	40.55	do.	29.56	82.5	.74	.14		63.0	75.0	325.5	53.0	170	676	2,838
465	Ill. No. 29A	4	do.	11,30,06	9.98	40.55	do.	29.73	75.5	.81	.15		47.0	53.0	320.2	45.0	147	683	2,665
460	Ill. No. 29B	4	do.	11,23,06	10.05	40.55	do.	29.94	81.5	.80	.18		43.0	57.0	324.8	46.0	163	642	2,759
461	do.	4	do.	11,24,06	5.42	40.55	do.	29.89	80.5	.84	.18		36.0	53.0	324.0	45.0	159	642	2,816
466	do.	4	do.	12,1,06	10.07	40.55	do.	29.85	79.5	.82	.16		41.0	52.0	323.3	45.0	162	660	2,784
511	Ill. No. 30	4	do.	2,20,07	8.58	40.55	do.	29.26	79.5	.87	.19		45.0	59.0	323.3	41.0		710	
489	Ill. No. 31	4	do.	1,7,07	9.47	40.55	do.	29.55	74.0	.74	.14		68.0	75.0	319.1	42.0	169	634	
491	do.	4	do.	1,9,07	9.75	40.55	do.	29.82	82.0	.87	.20		27.0	47.0	325.2	44.0	178	631	
513	Ill. No. 33	4	do.	2,22,07	8.68	40.55	do.	29.87	82.0	1.01	.10	+ .34	25.0	48.0	325.2	42.0		689	2,465
509	Ill. No. 34B	4	do.	2,18,07	9.00	40.55	do.	29.11	82.0	.83	.22		61.0	73.0	325.2	40.0		712	
71	Ind. No. 1	2	do.	12,3,04	6.60	40.55	do.	29.85	83.0	.54	.14	.00	31.0	51.0	325.8	46.9	171	616	
68	do.	2	do.	11,29,04	9.93	40.55	do.	29.40	83.3	.48	.13	.00	50.5	64.1	325.9	47.0	174	616	
65	Ind. No. 2	2	do.	11,26,04	10.13	40.55	do.	29.97	97.9	.52	.16	.00	38.8	57.7	336.3	50.2	191	597	
162	Ind. No. 3	1	do.	8,10,05	9.65	40.55	do.	29.47	76.0	.51	.15		85.0	91.0	320.4	74.0	197	566	2,351
151	Ind. No. 4	1	do.	7,28,05	10.05	40.55	do.	29.41	73.0	.48	.12		82.0	85.0	318.1	74.0	197	556	2,023
165	do.	2	Rocking	8,15,05	10.03	36.40	do.	29.26	77.0	.61	.19		85.0	89.0	321.2	76.0	199	515	2,062
166	do.	2	do.	8,16,05	8.80	36.40	do.	29.42	73.0	.60	.22		80.0	85.0	318.1	78.0	197	521	1,870
154	do.	1	Plain	8,1,05	9.95	40.55	do.	29.53	78.0	.45	.11		82.0	89.0	322.0	74.0	195	589	2,290
153	Ind. No. 5	1	do.	7,31,05	10.02	40.55	do.	29.50	69.0	.51	.22		82.0	89.0	314.8	73.0	186	571	2,391
155	do.	1	do.	8,2,05	9.98	40.56	do.	29.52	77.0	.50	.18		85.0	92.0	321.2	74.0	194	566	2,223
156	do.	1	do.	8,3,05	9.92	40.55	do.	29.47	75.5	.53	.18		73.0	81.0	320.0	73.0	182	573	2,317
157	Ind. No. 6	1	do.	8,4,05	9.97	40.55	do.	29.45	77.0	.49	.15		84.0	90.0	321.2	74.0	195	591	2,410
159	do.	1	do.	8,7,05	9.92	40.55	do.	29.51	78.0	.43	.11		81.0	88.0	322.0	74.0	200	613	2,522
158	Ind. No. 7A	1	do.	8,5,05	10.02	40.55	do.	29.44	75.0	.44	.12		88.0	93.0	319.7	74.0	200	561	2,579
288	do.	2	Rocking	1,10,06	9.78	36.40	do.	29.65	67.5	.55	.23		36.0	57.0	313.5	42.0	166	620	2,338
164	Ind. No. 7B	2	do.	8,14,05	10.03	36.40	do.	29.27	82.0	.62	.23		83.0	87.0	325.0	74.0	197	549	1,880
176	do.	1	Plain	8,28,05	10.07	40.55	do.	29.63	78.5	.56	.17		82.0	88.0	322.4	77.0	201	582	2,033
182	Ind. No. 8	1	do.	9,4,05	9.98	40.55	do.	29.59	72.0	.49	.16		69.0	72.0	317.3	77.0	199	617	2,384

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Boiler No.	Kind of grate or stoker.	Trial. Date.	Trial. Duration (hours).	Grate surface (square feet).	Kind of draft.	Average pressure. Barometer (inches of mercury).	Average pressure. Steam gage (pounds per square inch).	Average pressure. Force of draft (inches of water). Hood.	Average pressure. Force of draft (inches of water). Furnace.	Average pressure. Under fire.	Average temperatures (°F.). External air.	Average temperatures (°F.). Fire room.	Average temperatures (°F.). Steam.	Average temperatures (°F.). Feed water. In tank.	Average temperatures (°F.). Feed water. Entering boiler.	Average temperatures (°F.). Escaping gases.	Average temperatures (°F.). Furnace.
1	2	14	15	16 (1)	17 (2)	18 (3)	19 (6.4)	20 (11)	21 (11.1)	22 (12)	23 (13)	24 (14)	25 (15)	26 (16)	27 (17)	28 (18)	29 (20)	30 (21)	31 (22.1)
183	Index No. 8	1	Plain	9,5,05	10.00	40.55	Natural	29.68	81.0	.41	.13	......	69.0	74.0	324.3	76.0	206	600	2,279
185	do	1	do	9,7,05	10.00	40.55	do	29.61	73.5	.51	.16	......	70.0	76.0	318.5	75.0	204	631	2,304
184	do	1	do	9,6,05	10.00	40.55	do	29.67	70.0	.43	.10	......	65.0	69.0	315.6	76.0	195	630	2,354
168	Ind. No. 9A	2	Rocking	8,18,05	9.92	36.40	do	29.42	77.0	.53	.12	......	83.0	88.0	321.2	78.5	204	566	2,349
169	do	2	do	8,19,05	10.02	36.40	do	29.36	79.0	.49	.13	......	79.0	86.0	322.8	78.0	200	586	2,239
174	Ind. No. 9B	1	Plain	8,25,05	6.70	40.55	do	29.59	76.0	.56	.15	......	75.0	83.0	320.4	79.0	196	595	2,064
334	Ind. Nos. 9A and 9B.	1	do	2,23,06	3.92	40.55	do	29.32	75.5	.72	.23	......	52.0	57.0	320.0	41.0	130	700	2,925
167	Ind. No. 10	2	Rocking	8,17,05	10.05	36.40	do	29.45	77.0	.60	.18	......	77.0	85.0	321.2	78.0	203	522	2,201
177	do	1	Plain	8,29,05	10.00	40.55	do	29.62	82.5	.45	.09	......	84.0	89.0	325.4	77.5	201	614	2,473
233	Ind. No. 11	2	Rocking	11,6,05	9.65	36.40	do	29.46	73.5	.51	.11	......	50.0	64.0	318.5	55.0	170	658	2,577
234	do	2	do	11,7,05	9.62	36.40	do	29.28	71.5	.48	.12	......	53.0	......	316.8	54.0	184	624	2,378
235	do	2	do	11,8,05	9.95	36.40	do	29.39	72.5	.50	.15	......	47.0	......	317.7	54.0	184	625	2,494
299	Ind. No. 12	2	do	1,22,06	10.08	36.40	do	29.25	71.0	.50	.16	......	23.0	51.0	316.4	43.0	168	611	2,359
300	do	2	do	1,23,06	10.05	36.40	do	29.74	73.0	.54	.19	......	23.0	49.0	318.1	42.5	177	634	2,397
310	do	1	Plain	2,1,06	9.48	40.55	do	29.61	71.5	.49	.11	......	42.0	65.0	316.8	40.0	125	a 350	2,722
432	Ind. No. 13	2	do	9,12,06	10.08	40.55	do	29.30	79.5	.69	.13	......	84.0	90.0	323.3	79.5	148	590	2,290
433	do	2	do	9,13,06	3.75	40.55	do	29.43	78.0	.74	.16	......	68.0	75.0	322.2	79.0	133	586	2,260
430	Ind. No. 14	2	do	9,7,06	9.92	40.55	do	29.40	78.0	.69	.18	......	81.0	86.0	322.2	76.5	157	589	......
431	do	2	do	9,10,06	10.00	40.55	do	29.32	79.5	.68	.16	......	86.0	90.0	323.3	78.0	156	585	......
428	Ind. No. 15	2	do	9,4,06	9.70	40.55	do	29.42	75.5	.76	.14	......	71.0	77.0	320.2	77.5	148	682	......
429	do	2	do	9,5,06	10.05	40.55	do	29.45	76.5	.73	.13	......	75.0	80.0	321.0	77.0	159	626	......
426	Ind. No. 16	2	do	8,31,06	10.03	40.55	do	29.51	72.0	.69	.13	......	80.0	85.0	317.4	77.5	154	598	......
427	do	2	do	9,1,06	9.00	40.55	do	29.44	75.5	.67	.15	......	84.0	89.0	320.2	77.5	164	599	......
441	Ind. No. 17	4	do	10,18,06	9.88	40.55	do	29.21	76.5	.75	.13	......	68.0	79.0	321.0	61.5	169	661	2,545
442	do	4	do	10,19,06	10.13	40.55	do	29.48	76.0	.74	.15	......	70.0	77.0	320.6	62.0	177	638	2,544
435	Ind. No. 18B	4	do	10,4,06	10.10	40.55	do	29.17	81.5	.64	.05	......	60.0	84.0	324.8	69.0	157	582	......
436	do	4	do	10,5,06	9.67	40.55	do	29.30	78.5	.73	.07	......	47.0	71.0	322.5	69.0	161	614	......
464	Ind. No. 19	4	do	11,28,06	7.57	40.55	do	29.96	75.5	.79	.16	......	38.0	45.0	320.2	45.0	153	620	2,618

10	Ind. T. No. 1	1	do	9, 22, 04	9.75	40.55	do		94.8	.31	.12	.00	68.3	71.8	334.2	71.6	171	600	
20	Ind. T. No. 2	2	do	10, 5, 04	10.17	40.55	do	29.56	91.0	.34	.12	.00	70.4	76.2	331.5	73.0	180	538	2,087
417	Ind. T. No. 2B	2	do	8, 8, 06	10.15	40.55	do	29.34	79.0	.58	.09		83.0	88.0	322.9	80.5	155	588	
418	do	2	do	8, 9, 06	10.05	40.55	do	29.30	76.0	.63	.11		85.0	90.0	320.6	80.0	153	592	
455	do	4	do	11, 9, 06	9.92	40.55	do	29.51	81.0	.76	.14		57.0	70.0	324.4	54.0	160	660	2,807
453	do	4	do	11, 7, 06	10.05	40.55	Natural, induced.	29.45	82.5	.78	.17		64.0	75.0	325.5	53.0	168	661	2,653
456	do	4	do	11, 12, 06	10.08	40.55	Natural	29.64	71.5	.87	.14		38.0	55.0	317.0	54.0	156	727	2,704
32	Ind. T. No. 3	1	do	10, 19, 04	10.02	40.55	do	29.28	86.2	.49	.18	.00	72.0	76.0	328.0	66.0	158	613	
52	Ind. T. No. 4	1	do	11, 10, 04	10.22	40.55	do	29.67	82.8	.59	.21	.00	40.0	61.5	325.7	57.8		614	
437	Ind. T. No. 8	4	do	10, 8, 06	7.45	40.55	do	29.26	76.5	.70	.05		61.0	85.0	321.0	68.0	159	625	
449	Ind. T. No. 9	4	do	10, 31, 06	10.02	40.55	do	29.93	80.0	.77	.16		43.0	60.0	323.7	57.0	181	641	2,513
450	do	4	do	11, 1, 06	9.97	40.55	do	29.86	77.5	.77	.12		46.0	65.0	321.8	55.0	191	649	2,738
45	Iowa No. 1	2	do	11, 3, 04	10.02	40.55	do	29.61	83.7	.46	.15	.00	60.5	67.4	326.3	57.4	195	534	
67	Iowa No. 2	2	do	11, 28, 04	9.92	40.55	do	29.23	82.5	.62	.21	.00	48.0	62.0	325.3	48.0	169	627	
49	Iowa No. 3	2	do	11, 8, 04	10.03	40.55	do	29.45	83.5	.58	.22	.00	53.4	61.5	326.1	56.1	190	578	
47	Iowa No. 4	2	do	11, 7, 04	10.00	40.55	do	29.45	88.0	.50	.19	.00	60.0	64.4	329.3	60.0	181	556	
66	do	1	do	11, 26, 04	10.03	40.55	do	29.07	98.2	.59	.22	.00	33.8	57.7	336.5	57.6		628	
55	Iowa No. 5	2	do	11, 14, 04	9.98	40.55	do	29.75	81.7	.51	.22	.00	42.4	53.5	324.9	51.4	177	530	
601	Jamestown No. 1.	5	Underfeed.	9, 12, 07	8.00	40.55	Forced, induced.	30.20	118.0	.39	.31	3.00	81.0	90.0	348.6	87.0		544	2,336
602	do	5	do	9, 13, 07	8.10	40.55	do	30.29	117.0	.35	.23	4.50	76.0	89.0	348.0	80.0		607	
603	Jamestown No. 3	5	do	9, 17, 07	8.12	40.55	do	30.19	114.5	.43	.28	4.10	86.0	97.0	346.6	87.5		622	2,298
604	do	5	do	9, 18, 07	8.00	40.55	do	30.14	118.0	.49	.28	4.70	87.0	98.0	348.6	80.0		651	2,347
605	do	5	do	9, 19, 07	8.25	40.55	do	30.13	116.0	.39	.25	3.70	80.0	91.0	347.4	80.0		612	2,205
606	do	6	Plain	9, 27, 07	9.00	40.55	Induced	30.17	101.0	.68	.14			79.0	338.3	77.5		420	2,264
607	do	6	do	9, 28, 07	9.07	40.55	do	29.93	101.5	.73	.11		76.0	81.0	338.6	76.5		458	2,016
608	Jamestown No. 4.	6	do	9, 30, 07	9.03	40.55	do	30.13	99.5	1.04	.18		74.0	82.0	337.3	76.0		484	2,192
609	do	6	do	10, 1, 07	4.88	40.55	do	30.25	102.0	1.87	.20	[a] .07	68.0	77.0	338.9	70.0		533	2,523
610	do	6	do	10, 2, 07	9.03	40.55	do	30.21	105.5	2.04	.21	.19	69.0	77.0	341.1	71.0		551	2,442
611	do	5	Underfeed.	10, 7, 07	9.00	40.55	Forced, induced.	30.02	121.0	.53	.51	1.20	83.0	91.0	350.3	74.5		540	1,920
612	do	5	do	10, 8, 07	9.00	40.55	do	29.93	116.5	.51	.50	1.10	73.0	87.0	347.7	72.5		525	2,053
613	do	5	do	10, 9, 07	9.00	40.55	do	30.21	119.0			.70	60.0	72.0	349.2	69.0		524	2,016
614	do	5	do	10, 10, 07	9.00	40.55	do	30.02	115.5			1.10	65.0	74.0	347.2	69.5		516	1,792
615	do	5	do	10, 11, 07	9.00	40.55	do	29.92	117.0	.50	.49	1.40	75.0	86.0	348.0	68.5		561	2,014
616	do	5	do	10, 12, 07	9.00	40.55	do	30.02	115.5	.53	.50	1.59	64.0	78.0	347.2	68.4		558	2,192
617	do	5	do	10, 15, 07	9.02	40.55	do	30.38	112.5	.51	.40	1.59	59.0	77.0	345.4	64.0		507	2,003
618	do	5	do	10, 16, 07	8.00	40.55	do	30.47	112.0	.51	.44	1.58	64.0	79.0	345.1	62.5		488	2,133
619	do	5	do	10, 17, 07	9.00	40.55	do	30.36	112.5	.51	.40	1.61	65.0	78.0	345.4	65.0		521	1,978
627	Jamestown No. 6.	5	do	10, 30, 07	9.00	40.55	do	30.33	114.0	.70	.34	2.90	53.0	72.0	346.3	56.5		705	2,381
630	do	5	do	11, 4, 07	9.00	40.55	do		115.0	.46	.34	1.90	61.0	76.0	346.9	57.0		535	2,136
631	do	5	do	11, 5, 07	8.98	40.55	do		112.0	.82	.29	4.90	65.0	84.0	343.1	56.5		676	2,575
620	Jamestown No. 7.	5	do	10, 18, 07	8.75	40.55	do	30.11	114.5	.50	.35	1.80	75.0	86.0	346.6	64.0		576	2,196
621	do	5	do	10, 21, 07	9.00	40.55	do	30.34	111.5	.51	.29	2.00	54.0	70.0	344.8	61.5		616	2,070
623	do	5	do	10, 23, 07	9.00	40.55	do	29.94	113.0	.61	.31	3.50	74.0	85.0	345.7	61.0		654	2,352
624	do	5	do	10, 24, 07	4.00	40.55	do	30.19	116.5	.70	.27	3.43	50.0	70.0	347.7	59.5		694	2,311
625	do	5	do	10, 28, 07	8.00	40.55	do	29.74	109.0	.63	.33	2.70	51.0	69.0	343.2	59.5		635	2,192
626	do	5	do	10, 29, 07	8.00	40.55	do	30.01	111.5	.67	.28	3.70	60.0	[a]72.0	344.8	57.5		696	2,296
639	Jamestown No. 11	6	Plain	11, 15, 07	9.05	40.55	Induced		100.0	.61	.20		50.0	59.0	337.6	50.0		540	2,678
6	Kans. No. 1	2	do	9, 15, 04	10.10	40.55	Natural	29.78	84.8	.43	.24	.00	67.5	72.8	327.0	75.0	194	567	
7	do	2	do	9, 16, 04	9.70	40.55	do		91.9	.39	.14	.00	77.3	83.3	332.1	74.0	192	602	
5	Kans. No. 2	2	do	9, 12, 04	7.00	40.55	do	29.75	84.0	.47	.22	.02	73.3	74.0	326.6	76.0	187	597	

[a] See notes on individual tests, p. 166.

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Boiler No.	Kind of grate or stoker.	Trial. Date.	Trial. Duration (hours).	Grate surface (square feet).	Kind of draft.	Average pressure. Barometer (inches of mercury).	Average pressure. Steam gage (pounds per square inch).	Average pressure. Force of draft (inches of water). Hood.	Average pressure. Force of draft (inches of water). Furnace.	Average pressure. Under fire.	Average temperatures (°F.). External air.	Average temperatures (°F.). Fire room.	Average temperatures (°F.). Steam.	Average temperatures (°F.). Feed water. In tank.	Average temperatures (°F.). Feed water. Entering boiler.	Average temperatures (°F.). Escaping gases.	Average temperatures (°F.). Furnace.
1	2	14	15	16 (1)	17 (2)	18 (3)	19 (6.4)	20 (11)	21 (11.1)	22 (12)	23 (13)	24 (14)	25 (15)	26 (16)	27 (17)	28 (18)	29 (20)	30 (21)	31 (22.1)
13	Kans. No. 2	1	Plain	9, 26, 04	9.38	40.55	Natural	29.40	91.3	.39	.16	.00	83.0	86.0	331.6	72.7	164	615	......
488	Kans. No. 2B	4	..do	1, 5, 07	7.70	40.55	....do	29.38	72.0	.80	.17	......	50.0	60.0	317.4	42.0	174	640	......
487	....do	4	..do	1, 4, 07	9.65	40.55	....do	29.60	80.0	.82	.17	......	34.0	53.0	323.7	41.0	177	613	......
495	....do	4	..do	1, 14, 07	9.72	40.55	....do	29.59	80.5	.84	.18	......	41.0	65.0	324.0	43.0	166	667	2,862
3	Kans. No. 3	2	..do	9, 7, 04	9.91	40.55	....do	29.64	71.7	.42	.14	.06	77.1	80.8	317.2	76.0	166	582	......
4	....do	2	..do	9, 9, 04	10.40	40.55	....do	29.53	78.5	.41	.25	......	79.1	86.2	322.5	78.0	197	535	......
58	Kans. No. 4	2	..do	11, 17, 04	10.05	40.55	....do	29.67	83.7	.51	.19	.00	56.0	69.6	326.3	49.2	152	531	......
72	Kans. No. 5	2	..do	12, 5, 04	9.90	40.55	....do	29.75	82.7	.52	.17	.00	36.7	53.2	325.6	43.8	173	615	......
311	Kans. No. 6	1	..do	2, 2, 06	9.98	40.55	....do	29.86	74.0	.58	.13	......	26.0	50.0	318.9	40.0	116	495	2,313
323	....do	1	..do	2, 13, 06	7.20	40.55	....do	29.37	71.0	.52	.15	......	46.0	64.0	316.4	38.0	103	532	2,670
60	Ky. No. 1	2	..do	11, 18, 04	10.03	40.55	....do	29.65	83.1	.40	.15	.00	59.4	71.0	325.9	49.9	186	540	......
255	Ky. No. 1C	1	..do	12, 2, 05	8.13	40.55	....do	29.66	74.5	.44	.12	......	36.0	......	319.3	49.0	125	666	......
263	....do	2	Rocking	12, 14, 05	9.98	36.40	....do	29.63	73.5	.47	.23	......	33.0	......	318.5	43.0	179	565	......
265	....do	1	Plain	12, 16, 05	6.83	40.55	....do	29.66	68.0	.46	.13	......	32.0	......	314.0	43.0	131	622	2,118
57	Ky. No. 2	2	..do	11, 16, 04	10.00	40.55	....do	29.80	82.9	.46	.16	.00	53.5	67.0	325.8	51.2	191	543	......
76	....do	2	..do	12, 9, 04	9.82	40.55	....do	29.21	82.0	.49	.17	.00	40.9	56.4	324.9	46.9	174	573	......
64	Ky. No. 3	2	..do	11, 25, 04	10.07	40.55	....do	29.73	84.4	.47	.12	.00	44.7	62.6	326.9	52.5	183	595	......
62	Ky. No. 4	2	..do	11, 22, 04	9.93	40.55	....do	29.58	80.3	.55	.19	.00	52.8	67.1	323.8	51.8	180	589	......
276	Ky. No. 5	2	Rocking	12, 29, 05	9.78	36.40	....do	29.22	75.0	.45	.15	......	39.0	58.0	319.7	42.5	148	651	2,799
277	....do	1	Plain	12, 30, 05	9.30	40.55	....do	29.47	74.5	.36	.08	......	40.0	59.0	319.3	42.5	119	620	......
270	Ky. No. 6	1	..do	12, 22, 05	10.02	40.55	....do	29.45	69.5	.37	.08	......	36.0	......	315.2	44.0	135	681	2,412
271	....do	1	..do	12, 23, 05	10.02	40.55	....do	29.44	71.0	.35	.05	......	31.0	52.0	316.4	44.0	132	692	2,426
273	Ky. No. 7	1	Rocking	12, 30, 05	9.60	36.40	....do	29.47	75.0	.37	.12	......	41.0	59.0	319.7	43.0	163	628	......
279	....do	5	Plain	1, 2, 06	9.22	36.40	....do	29.40	73.5	.41	.14	......	42.0	67.0	318.5	43.0	142	605	1,983
434	Ky. No. 8	4	..do	10, 3, 06	9.10	40.55	....do	29.20	87.0	.66	.05	......	53.0	79.0	328.8	69.0	172	596	......
443	....do	4	..do	10, 20, 06	9.72	40.55	....do	29.51	79.0	.79	.14	......	65.0	75.0	322.9	62.5	185	683	2,778
462	Ky. No. 9B	4	..do	11, 26, 06	10.00	40.55	....do	29.50	79.0	.70	.19	......	59.0	68.0	322.9	45.0	156	630	2,742
222	Md. No. 1	1	..do	10, 24, 05	10.00	40.55	....do	29.45	69.5	.49	.16	......	53.0	67.0	315.2	62.0	180	617	2,129
231	....do	2	Rocking	11, 3, 05	9.95	40.55	....do	29.42	75.0	.46	.11	......	52.0	......	319.7	55.0	172	611	2,398

232	....do..........	2	...do......	11, 4,05	9.97	36.40	.....do..........	29.47	74.5	.41	.12	....	51.0	......	319.3	55.0	172	591	2,350
490	Md. No. 2.......	4	Plain.....	1, 8,07	9.63	40.55	.....do..........	29.73	85.5	.83	.22	....	45.0	58.0	327.7	43.0	174	608	.....
493	....do..........	4	...do......	1,11,07	10.00	40.55	.....do..........	29.15	83.0	.85	.21	....	40.0	61.0	325.9	43.0	....	674	.....
518	....do..........	4	...do......	3, 1,07	5.42	20.30	.....do..........	29.29	74.5	.29	.16	....	47.0	61.0	319.4	40.0	....	556	.....
12	Mo. No. 1.......	1	...do......	9,24,04	10.00	40.55	.....do..........	29.59	87.4	.40	.17	.02	71.0	80.0	329.5	71.0	174	614	.....
23	....do..........	2	...do......	10, 8,04	5.10	40.55	.....do..........	29.62	89.6	.44	.17	.00	73.0	76.0	330.5	69.1	182	532	.....
15	....do..........	1	...do......	9,28,04	9.91	40.55	.....do..........	29.59	85.9	.37	.16	.00	88.1	91.3	327.9	75.2	173	635	.....
37	Mo. No. 2.......	1	...do......	10,25,04	9.98	40.55	.....do..........	29.82	82.7	.62	.20	.00	52.4	60.0	325.6	58.5	168	623	.....
44	....do..........	2	...do......	11, 2,04	9.98	40.55	.....do..........	29.66	85.6	.32	.13	.00	59.0	66.0	327.7	57.3	198	483	.....
78	Mo. No. 3.......	2	...do......	12,12,04	9.95	40.55	.....do..........	29.61	77.5	.70	.28	.00	25.1	41.7	321.6	45.1	159	591	.....
77	....do..........	2	...do......	12,10,04	9.93	40.55	.....do..........	29.64	81.1	.65	.26	.00	30.6	49.2	324.4	45.2	168	608	.....
70	Mo. No. 4.......	2	...do......	12, 2,04	9.98	40.55	.....do..........	29.48	84.0	.52	.16	.00	35.5	54.5	326.5	46.2	177	625	.....
319	Mo. No. 5.......	1	...do......	2, 9,06	9.63	40.55	.....do..........	29.73	71.0	.61	.22	....	25.0	53.0	316.4	38.0	134	515	2,368
320	....do..........	1	...do......	2,10,06	8.35	40.55	.....do..........	29.96	69.0	.73	.34	....	25.0	48.0	314.8	38.0	....	520	.....
326	Mo. No. 6.......	1	...do......	2,16,06	9.92	40.55	.....do..........	29.81	73.5	.73	.19	....	27.0	49.0	318.5	38.0	118	568	2,476
327	....do..........	1	...do......	2,17,06	10.03	40.55	.....do..........	29.67	75.0	.75	.18	....	34.0	55.0	319.7	38.0	101	575	2,561
329	Mo. No, 7A......	1	...do......	2,20,06	9.78	40.55	.....do..........	29.26	69.5	.60	.14	....	61.0	67.0	315.2	38.0	149	585	.....
330	....do..........	1	...do......	2,21,06	5.73	40.55	.....do..........	29.35	72.0	.71	.13	....	45.0	59.0	317.3	39.0	147	588	.....
332	Mo. No. 7B......	1	...do......	2,22,06	9.75	40.55	Forced..........	29.35	72.5	.71	.02	....	54.0	63.0	317.7	40.0	142	746	2,686
486	Mo. No. 10......	4	...do......	1,3,07	9.63	40.55	Natural.........	29.43	80.0	.79	.15	....	49.0	58.0	323.7	41.0	180	627	.....
470	Mont. No. 2.....	4	...do......	12,7,06	6.50	40.55	.....do..........	29.80	76.5	.88	.23	....	26.0	49.0	321.0	45.0	159	642	.....
477	Mont. No. 3.....	4	...do......	12,15,06	8.97	40.55	.....do..........	29.69	79.5	.86	.14	....	34.0	51.0	323.3	45.0	182	654	.....
27	N. Mex. No. 1...	2	...do......	10,13,04	10.05	40.55	.....do..........	29.77	86.7	.36	.14	.00	63.0	70.0	328.5	69.0	171	556	.....
26	N. Mex. No. 2...	2	...do......	10,12,04	10.00	40.55	.....do..........	29.67	86.1	.49	.23	.00	66.4	72.0	328.1	70.0	162	545	.....
30	....do..........	1	...do......	10,17,04	8.12	40.55	.....do..........	29.59	84.4	.54	.21	.00	76.0	78.0	326.8	67.2	164	598	2,067
396	N. Mex. No. 3A..	1	...do......	6,15,06	10.00	40.55	.....do..........	29.34	82.0	.60	.22	....	74.0	75.0	325.0	72.5	187	659	2,333
389	N. Mex. No. 3B..	1	...do......	6,6,06	10.00	40.55	.....do..........	29.13	78.0	.54	.18	....	89.0	90.0	322.0	74.0	176	675	2,225
391	....do..........	1	...do......	6,9,06	10.00	40.55	.....do..........	29.31	77.0	.57	.21	....	86.0	86.0	321.2	75.5	182	670	2,432
392	....do..........	1	...do......	6,11,06	9.37	40.55	.....do..........	29.43	78.5	.64	.22	....	75.0	78.0	322.4	76.5	193	720	2,420
397	N. Mex. No. 4A..	1	...do......	6,25,06	10.00	40.55	.....do..........	29.39	80.5	.64	.25	....	79.0	79.0	323.9	71.5	....	671	2,336
398	....do..........	1	...do......	6,26,06	10.07	40.55	.....do..........	29.37	82.0	.65	.25	....	86.0	90.0	325.0	74.0	202	673	2,534
395	N. Mex. No. 4B..	1	...do......	6,14,06	10.08	40.55	.....do..........	29.27	81.0	.61	.22	....	63.0	65.0	324.2	73.0	195	665	2,285
387	N. Mex. No. 5...	1	...do......	6,4,06	10.07	40.55	.....do..........	29.33	79.5	.58	.21	....	85.0	85.0	323.1	73.0	171	675	2,371
33	N. Dak. No. 1...	1	...do......	10,20,04	9.84	40.55	.....do..........	29.28	62.9	.58	.33	....	61.4	66.0	309.4	66.0	138	494	.....
206	N. Dak. No. 3...	2	Rocking...	10,5,05	5.72	36.40	Forced..........	29.56	75.5	.65	.10	....	72.0	74.0	320.0	71.5	192	580	2,093
191	Ohio No. 1......	2	...do......	9,15,05	9.92	36.40	Natural.........	29.48	74.0	.52	.15	....	77.0	83.0	318.9	74.0	203	544	2,194
192	....do..........	2	...do......	9,16,05	10.07	36.40	.....do..........	29.42	69.5	.53	.18	....	68.0	74.0	315.2	72.5	194	575	2,384
193	Ohio No. 2......	2	...do......	9,18,05	9.95	36.40	.....do..........	29.35	77.0	.51	.18	....	83.0	87.0	321.2	73.5	200	591	2,293
197	....do..........	1	Plain.....	9,23,05	9.87	40.55	.....do..........	29.66	72.0	.45	.20	....	75.0	81.0	317.3	72.5	203	544	2,294
203	Ohio No. 3......	2	Rocking...	9,30,05	9.78	36.40	.....do..........	29.37	75.0	.47	.12	....	72.0	78.0	319.7	73.0	194	607	2,434
188	Ohio No. 4......	1	Plain.....	9,11,05	9.13	40.55	.....do..........	29.51	72.5	.47	.17	....	72.0	76.0	317.7	73.0	195	619	2,426
201	....do..........	2	Rocking...	9,28,05	9.98	36.40	.....do..........	29.52	73.5	.47	.18	....	79.0	83.0	318.5	72.5	196	560	2,196
202	....do..........	2	...do......	9,29,05	9.38	36.40	.....do..........	29.44	73.0	.55	.21	....	80.0	86.0	318.1	72.5	187	577	2,289
219	....do..........	1	Plain.....	10,20,05	9.92	40.55	.....do..........	29.67	71.5	.42	.17	....	51.0	......	316.8	64.0	197	575	2,525
220	....do..........	1	...do......	10,21,05	10.00	40.55	.....do..........	29.67	79.5	.43	.09	....	49.0	......	323.1	64.0	195	611	2,359
221	....do..........	1	...do......	10,23,05	6.30	40.55	.....do..........	29.49	81.0	.42	.08	....	60.0	69.0	324.3	62.0	196	618	2,312
186	Ohio No. 5......	1	...do......	9,8,05	10.00	40.55	.....do..........	29.66	80.0	.41	.11	....	72.0	80.0	323.5	74.0	205	617	2,673
187	....do..........	1	...do......	9,9,05	10.00	40.55	.....do..........	29.62	80.0	.62	.16	....	72.0	78.0	323.5	73.5	194	695	2,441
189	....do..........	1	...do......	9,12,05	10.05	40.55	.....do..........	29.56	71.0	.42	.13	....	77.0	81.0	316.4	73.0	193	600	2,440
190	....do..........	1	...do......	9,13,05	10.07	40.55	.....do..........	29.67	69.0	.40	.10	....	73.0	77.0	314.8	73.0	161	624	2,503
284	Ohio No. 6......	2	Rocking...	1,6,06	9.93	36.40	.....do..........	29.76	71.5	.41	.12	....	38.0	55.0	316.8	42.5	179	619	2,334
253	....do..........	1	Plain.....	11,29,05	8.20	40.55	.....do..........	29.59	68.5	.45	.18	....	29.0	......	314.4	52.0	128	648	2,332
268	Ohio No. 7......	1	...do......	12,20,05	9.92	40.55	.....do..........	29.10	69.5	.40	.13	....	38.0	......	315.2	43.0	137	660	2,280

TABLE 4.—*Observed data and computed results of steaming tests at St Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A S. M. E. code number.]

No. of test.	Designation of coal.	Boiler No.	Kind of grate or stoker.	Trial. Date.	Trial. Duration (hours).	Grate surface (square feet).	Kind of draft.	Barometer (inches of mercury)	Average pressure.			r I n	Average temperatures (°F.).				r. ar- g ler.	Escaping gases.	Furnace.
1	2	14	15	16 (1)	17 (2)	18 (3)	19 (6.4)	20 (11)				)2					20)	30 (21)	31 (22.1)
269	Ohio No. 7	1	Plain	12,21,05	8.27	40.55	Natural	29.08	69.5	0.55	0.18	......	38.0	......	315.2	44.0	141	677	2,453
287	Ohio No 8.	2	Rocking	1,9,06	10.03	36.40	do	29.79	70.0	.50	.21	......	26.0	47.0	315.6	42.0	166	632	2,596
246	Ohio No. 9A	1	Plain	11,21,05	8.00	40.55	do	29.89	71.5	.43	.15	......	45.0	......	316.8	52.0	140	600	2,400
249	do	1	do	11,24,05	9.80	40.55	do	29.26	71.0	.38	.13	......	56.0	......	316.4	51.0	151	592	2,411
250	do	1	do	11,25,05	10.00	40.55	do	29.26	70.5	.37	.11	......	39.0	......	316.0	51.0	161	617	2,322
252	do	1	do	11,28,05	6.63	40.55	do	28.97	74.0	.42	.14	......	80.0	......	318.5	51.5	147	668	2,436
224	Ohio No. 9B	2	Rocking	10,26,05	9.88	36.40	do	29.45	69.0	.50	.18	......	52.0	......	314.8	60.0	188	569	1,982
241	do	1	Plain	11,15,05	8.08	40.55	do	29.03	72.0	.47	.11	......	59.0	......	317.3	52.5	124	614	2,349
243	do	1	do	11,17,05	9.45	40.55	do	29.30	71.5	.49	.13	......	65.0	......	316.8	52.0	127	584	2,457
244	do	1	do	11,17,05	6.07	40.55	do	29.20	71.0	.44	.11	......	53.0	......	316.4	52.0	139	604	2,532
469	Ohio No. 10	4	do	12,6,06	10.02	40.55	do	29.50	74.0	.81	.19	......	42.0	57.0	319.1	46.0	164	684	2,577
474	Ohio No. 11	4	do	12,12,06	9.22	40.55	do	29.52	79.0	.78	.20	......	52.0	62.0	322.9	45.0	163	622	2,748
475	do	4	do	12,13,06	9.28	40.55	do	29.32	77.5	.77	.19	......	60.0	69.0	321.8	44.5	178	640	2,893
483	Ohio No. 12	4	do	12,22,06	9.05	40.55	do	29.76	75.0	.85	.21	......	27.0	55.0	319.8	40.0	156	664	......
1	Pa. No. 1	2	do	8,31,04	9.88	40.55	do	29.60	82.4	.48	.17	.03	79.4	84.3	325.4	76.0	167	585	......
2	Pa. No. 2	2	do	9,6,04	10.08	40.55	do	29.69	78.0	.31	.15	.01	76.0	82.0	322.2	76.0	176	536	......
36	Pa. No. 3	1	do	10,24,04	10.08	40.55	do	29.47	83.6	.61	.25	.00	67.2	69.6	326.2	58.8	153	624	......
74	Pa. No. 4	2	do	12,7,04	9.88	40.55	do	29.51	85.1	.45	.19	.00	44.4	61.3	327.8	44.3	170	574	......
207	do	2	Rocking	10,6,05	10.00	36.40	do	29.62	81.0	.44	.14	......	74.0	80.0	324.3	72.0	190	544	2,363
208	do	2	do	10,7,05	10.00	36.40	do	29.15	79.5	.44	.13	......	73.0	80.0	323.1	72.0	171	552	2,223
209	do	2	do	10,9,05	10.05	36.40	do	29.51	79.5	.49	.15	......	69.0	76.0	323.1	70.5	166	575	2,200
266	Pa. No. 5	2	do	1,8,06	10.00	36.40	do	29.85	70.5	.36	.12	......	20.0	45.0	316.0	42.0	148	616	2,628
194	do	2	do	9,19,05	10.00	36.40	do	29.50	80.5	.51	.14	......	68.0	74.0	323.9	74.0	205	592	2,478
195	do	2	do	9,20,05	10.02	36.40	do	29.61	79.5	.47	.16	......	71.0	77.0	323.1	73.0	197	543	2,532
217	Pa. No. 6	1	Plain	10,18,05	9.90	40.55	do	29.27	71.0	.46	.13	......	63.0	......	316.4	64.5	185	544	2,425
218	do	1	do	10,19,05	9.95	40.55	do	29.29	70.0	.49	.17	......	69.0	......	315.6	64.5	191	583	2,251
333	do	1	do	2,23,06	4.13	40.55	do	29.32	78.5	.73	.25	......	51.0	58.0	322.4	41.0	178	698	2,601
198	Pa. No. 7	1	do	9,25,05	10.08	40.55	do	29.59	71.0	.48	.16	......	72.0	77.0	316.4	72.5	194	611	2,001
307	do	1	do	1,30,06	10.07	40.55	do	29.50	73.5	.54	.13	......	47.0	63.0	318.5	39.0	145	559	2,220
199	do	1	do	9,26,05	10.08	40.55	do	29.57	81.0	.39	.12	......	72.0	76.0	324.3	72.5	211	575	2,230

236	Pa. No. 8	2	Rocking	11,9,05	9.88	36.40	do	29.67	70.5	.43	.15		40.0		316.0	53.5	193	591	2,317
237	do	2	do	11,10,05	10.00	36.40	do	29.82	75.5	.45	.16		40.0		320.0	54.0	182	563	2,266
238	do	2	do	11,11,05	10.02	36.40	do		72.5	.50	.17		34.0		318.2	53.5	191	602	2,212
239	do	2	do	11,13,05	9.92	36.40	do	29.30	75.0	.63	.19		56.0		319.7	53.0	192	609	
242	do	1	Plain	11,16,05	7.88	40.55	do	29.28	71.5	.47	.16		59.0		316.8	52.0	136	575	2,059
227	Pa. No. 10	2	Rocking	10,30,05	10.00	36.40	do	29.69	67.0	.52	.16		44.0		313.1	57.5	154	599	
228	do	2	do	10,31,05	9.97	36.40	do	29.57	64.5	.48	.16		41.0		310.9	57.0	169	567	2,329
229	do	2	do	11,1,05	10.00	36.40	do	29.57	85.0	.56	.15		42.0		327.2	56.5	190	642	2,445
472	Pa. No. 15	4	Plain	12,10,06	8.75	40.55	do	29.85	80.5	.81	.27		41.0	57.0	324.0	45.0	165	639	2,512
473	do	4	do	12,11,06	9.77	40.55	do	29.92	65.0	.82	.23		39.0	53.0	311.5	45.0	154	583	2,615
467	do	4	do	12,3,06	8.87	40.55	do	29.51	81.0	.76	.17		49.0	60.0	324.4	45.0	184	601	2,753
468	Pa. No. 16	4	do	12,5,06	8.10	40.55	do	29.08	77.5	.73	.14		62.0	68.0	321.8	44.0	171	629	2,855
471	do	4	do	12,8,06	10.03	40.55	do	29.43	76.5	.76	.20		54.0	64.0	321.0	45.0	159	624	2,785
496	Pa. No. 17	4	do	1,15,07	10.00	40.55	do	29.65	78.5	.86	.21		31.0	54.0	322.5	43.0	164	640	2,768
506	do	4	do	2,13,07	9.23	40.55	Forced	29.34	77.5	.76	.06	+.32	65.0	74.0	321.8	38.0		671	2,444
499	Pa. No. 18	4	do	1,24,07	8.58	40.55	Natural	29.47	81.0	.81	.19		54.0	70.0	324.4	40.0	162	757	2,854
415	do	4	do	2,25,07	9.22	40.55	do	29.65	81.0	.84	.18		43.0	59.0	324.4	40.0		740	2,709
498	Pa. No. 19	4	do	1,17,07	9.50	40.55	do	29.47	77.5	.86	.19		39.0	61.0	321.8	41.0	163	648	2,828
508	do	4	do	2,15,07	9.38	40.55	do	29.48	83.5	.97	.23		55.0	66.0	326.2	39.0		651	
512	Pa. No. 20	4	do	2,21,07	7.77	40.55	do	29.60	79.0	.93	.19		29.0	50.0	322.9	41.0		699	
514	do	4	do	2,23,07	7.93	40.55	do	29.66	78.5	.93	.23		29.0	51.0	323.5	41.0		784	
510	Pa. No. 22	4	do	2,19,07	9.17	40.55	Forced	29.27	80.0	.86	.08	.46	44.0	61.0	323.7	41.0		686	
401	R. I. No. 1	1	do	6,29,06	8.05	40.55	do	29.39	76.0	.54	.18	.40	93.0	96.0	320.4	79.0	189	589	
344	Tenn. No. 1	1	do	3,14,06	10.00	40.55	Natural	29.45	75.5	.55	.15		30.0	58.0	320.0	41.5		616	2,499
345	do	1	do	3,15,06	7.28	40.55	do	29.45	77.0	.80	.18		29.0	49.0	321.2	38.0	140	673	2,458
346	do	1	do	2,16,06	7.03	40.55	do	29.60	74.0	.74	.20		28.0	50.0	318.9	37.0	122	645	2,393
411	do	1	do	7,19,06	4.48	40.55	do	29.45	86.0	.62	.10		89.0	98.0	328.1	80.0	167	704	2,775
409	do	1	do	7,17,06	10.08	40.55	do	29.35	89.0	.65	.13		82.0	95.0	330.2	80.0	187	698	2,468
367	Tenn. No. 2	1	do	4,18,06	9.97	40.55	do	29.61	79.0	.68	.19		67.0	73.0	322.8	67.0	165	666	2,788
368	do	1	do	4,19,06	9.98	40.55	do	29.52	79.0	.48	.11		74.0	80.0	322.8	58.0	166	588	2,488
369	do	1	do	4,20,06	9.97	40.55	do	29.45	82.0	.33	.08		70.0	76.0	325.0	58.5	178	580	2,250
349	Tenn. No. 3	1	do	3,21,06	8.97	40.55	do	29.36	77.5	.57	.14		42.0	61.0	321.6	39.0	139	528	2,664
350	do	1	do	3,22,06	10.00	40.55	do	29.73	76.0	.80	.14		32.0	54.0	320.4	38.0	155	592	2,562
355	Tenn. No. 4	1	do	3,28,06	10.00	40.55	do	29.57	75.0	.74	.16		43.0	60.0	319.7	69.0	176	554	2,584
356	do	1	do	3,29,06	9.98	40.55	do	29.39	79.5	.76	.22		40.0	60.0	323.1	82.0	164	600	2,719
405	do	1	do	7,13,06	8.25	40.55	do	29.31	88.0	.64	.18		82.0	93.0	329.5	80.0	195	669	2,294
352	Tenn. No. 5	1	do	3,24,06	9.98	40.55	do	29.88	81.0	.62	.13		36.0	53.0	324.3	38.5	174	554	2,456
357	do	1	do	3,30,06	10.00	40.55	do	29.15	75.5	.74	.21		37.0	58.0	320.0	85.0	194	585	2,575
358	do	1	do	3,31,06	10.00	40.55	do	29.40	79.0	.75	.20		43.0	59.0	322.8	83.0	181	577	2,520
379	Tenn. No. 6	1	do	5,4,06	9.88	40.55	do	29.06	75.0	.59	.14		80.0	81.0	319.7	67.0	196	512	
381	do	1	do	5,7,06	10.02	40.55	do	29.52	79.5	.70	.19		61.0	63.0	323.1	64.0	181	542	
372	Tenn. No. 7A	1	do	4,23,06	9.98	40.55	do	29.57	77.0	.48	.15		54.0	65.0	321.2	60.0	172	620	2,660
373	do	1	do	4,24,06	9.93	40.55	do	29.25	76.0	.69	.23		73.0	81.0	320.4	59.5	140	676	2,958
374	do	1	do	4,25,06	9.95	40.55	do	29.02	77.5	.49	.15		82.0	88.0	321.2	60.0	187	588	2,461
406	Tenn. No. 7B	1	do	7,14,06	6.15	40.55	do	29.31	81.5	.64	.17		82.0	96.0	324.8	80.0	191	684	2,420
384	Tenn. Nos. 8A8B	1	do	5,17,06	10.02	40.55	do	29.46	77.0	.58	.14		89.0	90.0	321.2	69.0	186	477	
385	do	1	do	5,18,06	10.08	40.55	Forced	29.39	79.5	.62		.25	85.0	86.0	323.1	71.0	181	501	2,243
388	do	1	do	6,5,06	10.03	40.55	Natural	29.21	80.0	.56	.18		80.0	80.0	323.5	73.5	172	685	2,309
363	Tenn. No. 9A	1	do	4,13,06	10.00	40.55	do	29.21	79.0	.65	.15		65.0	74.0	322.8	56.5	171	646	2,263
364	do	1	do	4,14,06	9.95	40.55	do	29.31	80.0	.70	.19		48.0	58.0	323.5	71.5	175	677	2,296
365	do	1	do	4,16,06	9.98	40.55	do	29.77	81.5	.71	.24		55.0	64.0	324.6	71.0	168	666	2,284
393	Tenn. No. 9B	1	do	6,12,06	10.13	40.55	do	*29.44	80.0	.62	.23		74.0	77.0	323.5	75.0	196	690	2,276

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Boiler No.	Kind of grate or stoker.	Trial. Date.	Trial. Duration (hours).	Grate surface (square feet).	Kind of draft.	Average pressure. Barometer (inches of mercury).	Average pressure. Steam gage (pounds per square inch).	Average pressure. Force of draft (inches of water). Hood.	Average pressure. Force of draft (inches of water). Furnace.	Average pressure. Under fire.	Average temperatures (°F.). External air.	Average temperatures (°F.). Fire room.	Average temperatures (°F.). Steam.	Average temperatures (°F.). Feed water. In tank.	Average temperatures (°F.). Feed water. Entering boiler.	Average temperatures (°F.). Escaping gases.	Average temperatures (°F.). Furnace.
1	2	14	15	16 (1)	17 (2)	18 (3)	19 (6.4)	20 (11)	21 (11.1)	22 (12)	23 (13)	24 (14)	25 (15)	26 (16)	27 (17)	28 (18)	29 (20)	30 (21)	31 (22.1)
407	Tenn. No. 10	1	Plain	7,16,06	4.72	40.55	Natural	29.35	80.5	.68	.18	......	72.0	80.0	324.0	79.0	173	669	1,984
408	.....do	1	...do	7,16,06	3.87	40.55	.....do	29.30	78.0	.68	.15	......	80.0	88.0	322.2	79.0	169	693	2,226
22	Tex. No. 1	2	...do	10,7,04	8.77	40.55	.....do	29.70	90.0	.52	.34	.00	64.4	70.0	330.8	69.0	149	421	......
291	Tex. No. 4	1	...do	1,13,06	10.18	40.55	Forced	29.32	63.5	.70	......	.49	37.0	58.0	310.1	42.0	114	582	2,119
298	.....do	2	Rocking	1,20,06	7.15	36.40	.....do	29.03	78.0	.61	.19	......	73.0	78.0	321.6	42.0	177	646	2,269
303	.....do	2	...do	1,26,06	4.32	36.40	.....do	29.85	72.5	.65	......	......	32.0	54.0	317.7	39.0	153	652	2,299
402	Utah No. 2	1	Plain	7,11,06	6.15	40.55	Natural	29.45	82.5	.65	.18	......	86.0	100.0	325.5	79.0	201	667	2,054
403	.....do	1	...do	7,11,06	2.75	40.55	.....do	29.36	78.0	.43	.20	......	94.0	111.0	322.2	79.0	176	589	2,253
404	.....do	1	...do	7,12,06	10.08	40.55	.....do	29.36	84.0	.55	.22	......	87.0	98.0	326.6	79.5	191	587	......
281	Va. No. 1	2	Rocking	1,3,06	9.75	36.40	.....do	28.75	77.0	.41	.14	......	45.0	63.0	320.8	42.0	183	636	2,637
282	.....do	2	...do	1,4,06	9.83	36.40	.....do	28.96	75.5	.38	.11	......	35.0	55.0	319.7	42.0	182	631	2,542
247	Va. No. 2	1	Plain	11,22,05	8.00	40.55	.....do	29.78	71.5	.44	.10	......	52.0	......	316.8	51.0	120	631	2,548
251	.....do	1	...do	11,27,05	8.00	40.55	.....do	29.33	72.0	.41	.10	......	52.0	......	317.3	51.0	137	670	2,515
256	.....do	2	Rocking	12,4,05	8.43	36.40	.....do	29.94	75.0	.44	.15	......	26.0	......	319.7	46.5	169	608	2,673
200	.....do	2	...do	12,11,05	9.87	36.40	.....do	29.32	71.5	.34	.13	......	50.0	......	316.8	44.0	160	609	2,671
280	Va. No. 3	2	...do	1,2,06	9.88	36.40	.....do	29.40	73.5	.42	.15	......	42.0	67.0	318.5	43.0	159	613	2,452
283	.....do	2	...do	1,5,06	10.00	36.40	.....do	29.37	72.0	.37	.16	......	39.0	57.0	317.3	42.5	181	583	2,537
240	Va. No. 4	1	Plain	11,14,05	9.70	40.55	.....do	29.44	70.5	.53	.22	......	38.0	......	316.0	53.0	128	559	2,224
248	.....do	1	...do	11,23,05	8.02	40.55	.....do	29.50	69.5	.46	.11	......	59.0	......	315.2	51.0	134	634	2,483
254	.....do	1	...do	12,1,05	10.00	40.55	.....do	29.67	74.5	.44	.13	......	32.0	......	319.3	50.0	126	635	2,582
476	Va. No. 5A	4	...do	12,14,06	9.40	40.55	Natural, forced	29.43	68.0	.83	.22	.32	50.0	59.0	314.1	45.0	177	618	......
482	.....do	4	...do	12,21,06	6.53	40.55	Forced	29.45	81.0	1.03	.08	.63	34.0	46.0	324.4	41.0	151	711	......
494	Va. No. 5B	4	...do	1,12,07	7.00	40.55	Natural	29.33	81.5	.84	.20	......	40.0	65.0	324.8	43.0	174	652	......
507	Va. No. 6	4	...do	2,14,07	8.85	40.55	Forced	29.67	75.5	.87	.05	.24	44.0	67.0	320.2	39.0	......	676	......
290	Wash. No. 1B	1	...do	1,12,06	10.00	40.55	Natural	29.70	65.5	.59	.12	......	36.0	58.0	311.8	41.0	119	563	2,047
359	Wash. No. 2	1	...do	4,9,06	10.00	40.55	.....do	29.24	78.5	.60	.13	......	66.0	76.0	322.4	51.5	168	650	2,362
360	.....do	1	...do	4,10,06	10.05	40.55	.....do	29.44	79.5	.67	.12	......	60.0	70.0	323.1	52.0	174	625	2,469
361	.....do	1	...do	4,11,06	10.00	40.55	.....do	29.51	81.5	.68	.12	......	65.0	73.0	324.6	54.5	146	605	2,405
412	.....do	1	...do	7,20,06	9.47	40.55	.....do	29.38	84.5	.63	.11	......	89.0	95.0	327.0	80.5	186	690	2,155

24	W. Va. No. 1	2	Plain	10,10,04	9.98	40.55	Natural	29.36	87.8	.31	.13	.00	80.8	84.2	329.1	70.4	170	512	
25	W. Va. No. 2	2	...do	10,11,04	10.22	40.55	...do	29.55	85.4	.46	.24		07.9	74.2	327.5	70.0	163	541	
28	W. Va. No. 3	2	...do	10,14,04	9.97	40.55	...do	29.83	84.4	.50	.20	.00	61.0	68.0	326.8	58.0	170	592	
31	W. Va. No. 4	1	...do	10,18,04	10.00	40.55	...do	29.52	87.1	.48	.18	.00	74.0	79.0	328.9	66.3	103	577	2,247
34	W. Va. No. 5	1	...do	10,21,04	10.08	40.55	...do	29.14	85.7	.51	.19	.00	59.0	65.0	327.6	63.5	154	594	
39	W. Va. No. 6	1	...do	10,27,04	9.95	40.55	...do	29.75	83.6	.45	.16	.00	51.0	57.4	326.3	57.2	182	578	
43	...do	2	...do	11,1,04	10.18	40.55	...do	29.73	83.6	.46	.18	.00	61.0	68.0	326.3	56.0	196	521	
51	W. Va. No. 7	2	...do	11,10,04	10.18	40.55	...do	29.67	83.0	.53	.22	.00	40.0	61.0	325.8	56.0		566	
53	W. Va. No. 8	2	...do	11,11,04	9.98	40.55	...do	29.88	82.2	.37	.12	.00	42.0	60.0	325.3	54.8	193	541	
60	W. Va. No. 9	2	...do	11,30,04	10.00	40.55	...do	29.61	94.7	.50	.18	.00	36.0	53.5	334.0	48.0	179	576	
54	W. Va. No. 10	2	...do	11,12,04	9.93	40.55	...do	29.53	83.7	.38	.17	.00	39.7	56.1	326.3	54.0	185	583	
56	W. Va. No. 11	2	...do	11,15,04	9.97	40.55	...do	29.71	82.1	.52	.22	.00	51.7	64.3	325.2	49.3	188	559	
46	W. Va. No. 12	2	...do	11,4,04	10.13	40.55	...do	29.45	86.6	.44	.18	.00	62.4	69.8	328.3	57.3	197	534	
59	...do	1	...do	11,17,04	10.25	40.55	...do	29.67	83.6	.41	.14	.00	56.0	70.1	326.3	52.9		590	
179	W. V. No. 13	1	...do	8,31,05	10.00	40.55	...do	29.51	74.5	.37	.08		85.0	89.0	319.3	78.0	202	595	2,428
180	...do	1	...do	9,1,05	9.95	40.55	...do	29.43	75.0	.37	.10		89.0	91.0	319.7	79.0	211	586	2,312
178	W. Va. No. 14	1	...do	8,30,05	10.00	40.55	...do	29.57	75.0	.42	.16		83.0	89.0	319.7	78.0	198	592	2,337
181	...do	1	...do	9,2,05	7.60	40.55	...do	29.42	70.5	.50	.13		74.0	76.0	316.0	78.5	182	616	2,459
214	W. Va. No. 15	2	Rocking	10,14,05	8.78	36.40	...do	29.36	72.5	.53	.22		68.0		317.7	66.5	198	537	2,247
215	...do	1	Plain	10,16,05	9.75	40.55	...do	29.59	72.5	.40	.12		56.0		317.7	65.0	193	565	2,269
216	...do	1	...do	10,17,05	5.80	40.55	Forced	29.31	75.0	.41	.04		70.0		319.7	65.0	172	594	2,365
304	W. Va. No. 16A	2	Rocking	1,26,06	5.30	36.40	Natural	29.85	76.0	.42	.14		44.0	62.0	320.4	39.0	162	642	2,864
305	...do	1	Plain	1,27,06	5.33	40.55	...do	29.60	71.5	.49	.09		42.0	65.0	316.8	39.0	134	536	2,548
225	W. Va. No. 17	2	Rocking	10,27,05	9.92	36.40	...do	29.63	66.5	.53	.16		49.0		312.7	60.0	162	572	2,165
226	...do	2	...do	10,28,05	9.97	36.40	...do	29.92	70.0	.61	.17		42.0		315.6	59.0	166	593	
230	...do	2	...do	11,2,05	10.07	36.40	...do	29.35	74.0	.48	.19		46.0		318.9	55.0	184	573	2,392
201	W. Va. No. 18	2	...do	12,12,05	10.00	36.40	...do	29.34	76.0	.39	.13		45.0		320.4	43.0	186	625	2,590
202	...do	2	...do	12,13,06	10.07	36.40	...do	29.64	74.0	.50	.18		35.0	61.0	318.9	42.5	177	631	2,600
285	W. Va. No. 19	2	...do	1,7,06	9.97	36.40	...do	29.55	72.5	.45	.22		40.0	55.0	317.7	43.0	193	587	2,419
289	...do	1	Plain	1,11,06	8.00	40.55	...do	29.64	72.5	.56	.12		37.0	62.0	317.7	41.0	137	554	2,065
331	...do	1	...do	2,21,06	3.68	40.55	...do	29.45	69.0	.73	.12		53.0	58.0	314.8	39.0	137	595	2,700
272	W. Va. No. 20	2	Rocking	12,26,05	9.92	36.40	...do	29.33	75.5	.31	.09		46.0	56.0	320.0	43.0	187	576	
273	...do	2	...do	12,27,05	9.87	36.40	...do	29.22	75.5	.40	.10		46.0	55.0	320.0	43.0	165	593	2,274
264	...do	2	...do	12,15,05	9.97	36.40	...do	29.62	71.0	.38	.16		33.0		316.4	43.0	176	586	2,520
266	...do	1	Plain	12,18,05	10.00	40.55	...do	29.34	71.5	.35	.10		40.0		316.8	42.0	145	636	2,392
274	W. Va. No. 21	2	Rocking	12,28,05	7.30	36.40	...do	28.88	76.5	.49	.13		46.0	57.0	320.4	43.0	161	654	2,776
275	...do	1	Plain	12,29,05	9.05	40.55	...do	29.22	75.5	.54	.11		40.0	59.0	320.0	42.5	127	602	2,279
296	...do	1	...do	1,18,06	7.15	40.55	...do	29.29	79.0	.55	.10		44.0	60.0	322.8	42.0	119	557	2,561
267	...do	1	...do	12,19,05	10.02	40.55	...do	29.46	71.0	.40	.10		36.0		316.4	42.0	131	680	2,476
446	W. Va. No. 22A	4	...do	10,24,06	10.22	40.55	...do	29.25	76.0	.81	.17		58.0	64.0	320.6	62.0	168	651	2,616
447	...do	4	...do	10,25,06	9.68	40.55	...do	29.34	79.5	.81	.19		60.0	69.0	323.3	62.0	180	661	2,801
454	...do	4	...do	11,8,06	10.00	40.55	...do	29.44	82.0	.75	.16		62.0	71.0	325.2	53.5	166	657	2,793
438	W. Va. No. 22B	4	...do	10,9,06	9.55	40.55	...do	29.57	76.5	.79	.09		53.0	61.0	321.0	67.0	172	660	
439	W. Va. No. 23A	4	...do	10,16,06	9.95	40.55	...do	29.40	74.5	.77	.12		66.0	77.0	319.4	61.0	168	668	2,657
440	...do	4	...do	10,17,06	9.83	40.55	...do	29.25	75.5	.75	.12		68.0	80.0	320.2	61.0	177	656	2,572
444	W. Va. No. 23B	4	...do	10,22,06	10.05	40.55	...do	29.49	79.0	.78	.10		68.0	78.0	322.9	62.0	180	652	2,536
445	...do	4	...do	10,23,06	10.00	40.55	...do	29.34	79.5	.77	.13		65.0	73.0	323.3	62.0	151	661	2,638
63	Wyo. No. 1	2	...do	11,23,04	10.15	40.55	...do	29.42	81.2	.62	.23	.00	59.0	73.5	324.3	51.5	182	610	
61	Wyo. No. 2	2	...do	11,19,04	9.95	40.55	...do	29.49	81.6	.49	.14	.00	64.2	75.7	324.7	53.9	166	580	
196	Wyo. No. 2B	1	...do	9,22,05	9.88	40.55	...do	29.55	72.5	.59	.19		81.0	86.0	317.7	73.0	195	574	1,950
210	...do	2	Rocking	10,10,05	10.08	36.40	...do	29.53	74.0	.68	.20		58.0	68.0	318.9	71.0	159	589	2,067
213	...do	2	...do	10,13,05	10.03	36.40	Forced	29.35	77.0	.63	.08		71.0		321.2	67.5	183	628	2,228
211	Wyo. No. 3	2	...do	10,11,05	10.05	36.40	Natural	29.46	72.0	.63	.28		52.0		317.3	70.0	178	529	1,917

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Boiler No.	Kind of grate or stoker.	Trial. Date.	Trial. Duration (hours).	Grate surface (square feet).	Kind of draft.	Average pressure. Barometer (inches of mercury).	Average pressure. Steam gage (pounds per square inch).	Average pressure. Force of draft (inches of water). Hood.	Average pressure. Force of draft (inches of water). Furnace.	Average pressure. Under fire.	Average temperatures (°F.). External air.	Average temperatures (°F.). Fire room.	Average temperatures (°F.). Steam.	Average temperatures (°F.). Feed water. In tank.	Average temperatures (°F.). Feed water. Entering boiler.	Average temperatures (°F.). Escaping gases.	Average temperatures (°F.). Furnace.
1	2	14	15	16 (1)	17 (2)	18 (3)	19 (6.4)	20 (11)	21 (11.1)	22 (12)	23 (13)	24 (14)	25 (15)	26 (16)	27 (17)	28 (18)	29 (20)	30 (21)	31 (22.1)
212	Wyo. No. 3	2	Rocking	10, 12, 05	9.80	36.40	Natural, forced	29.40	74.5	.45	.01	......	56.0	70.0	319.3	69.0	198	583	2,142
223	....do	2	...do	10, 25, 05	8.95	36.40	Natural	29.44	64.0	.59	.23	......	49.0	......	310.5	61.0	180	546	1,972
399	Wyo. No. 4	1	Plain	6, 27, 06	10.02	40.55	....do	29.37	81.5	.60	.38	......	91.0	99.0	324.6	76.0	205	607	2,626
400	Wyo. No. 6	1	...do	6, 28, 06	10.02	40.55	....do	29.42	78.0	.62	.33	......	94.0	96.0	322.0	77.0	202	632	2,465
419	....do	2	...do	8, 10, 06	9.45	40.55	....do	29.30	69.0	.56	.24	......	87.0	91.0	314.9	80.5	151	497	......
	MISCELLANEOUS.																		
451	Argentine Republic No. 1	4	Plain	11, 5, 06	8.15	40.55	Forced	29.60	68.5	.60	.18	.71	70.0	78.0	314.6	55.0	141	491	......
458	....do	4	...do	11, 14, 06	8.88	40.55	....do	29.16	89.0	.76	.11	.53	37.0	55.0	330.2	51.0	168	574	2,014
485	....do	4	...do	1, 2, 07	2.80	40.55	....do	29.42	67.0	.80	.02	.55	47.0	59.0	313.2	40.0	162	641	......
172	Brazil No. 1	1	...do	8, 23, 05	5.35	40.55	Natural	29.53	77.0	.65	.16	......	83.0	92.0	321.2	78.5	198	590	1,900
173	....do	1	...do	8, 24, 05	5.60	40.55	Forced	29.48	74.5	.59	.03	.20	85.0	93.0	319.3	79.0	195	654	1,858
	Mixed coals (accurately sized):																		
348	1½ to 3 inches	1	...do	3, 20, 06	9.70	40.55	Natural	29.59	80.5	.76	.21	......	27.0	50.0	323.9	38.0	146	596	2,439
347	1 to 1½ inches	1	...do	3, 19, 06	5.65	40.55	....do	29.51	80.5	.76	.15	......	34.0	57.0	323.9	38.0	175	601	2,341
351	¾ to 1 inch	1	...do	3, 23, 06	7.05	40.55	....do	29.86	83.5	.68	.17	......	32.0	60.0	326.1	38.0	162	533	2,213
362	½ to ¾ inch	1	...do	4, 12, 06	5.32	40.55	....do	29.40	81.0	.59	.15	......	69.0	77.0	324.3	54.5	174	642	2,339
366	⅜ to ½ inch	1	...do	4, 17, 06	4.32	40.55	....do	29.76	80.5	.64	.26	......	53.0	61.0	323.9	92.5	176	618	2,363
370	¼ to ⅜ inch	1	...do	4, 21, 06	3.47	40.55	....do	29.38	84.0	.63	.22	......	71.0	73.0	326.5	59.5	175	614	2,225
371	Under ¼ inch	1	...do	4, 21, 06	5.15	40.55	....do	29.26	82.5	.60	.23	......	79.0	84.0	325.4	60.0	168	581	......
	Mixed coals:																		
245	Pa. No. 8 dried and Va. No. 4	1	...do	11, 20, 05	7.82	40.55	....do	29.69	73.0	.45	.12	......	46.0	......	318.1	52.0	144	614	2,338

414	Utah No. 1 and R. I. No. 1	1	...do	7, 24, 06	5.00	40.55	.....do	29.47	85.0	.07	.21	....	79.0	85.0	327.4	81.0	181	671	2,006
415	.......do	1	...do	7, 24, 06	5.00	40.55	Forced	29.38	75.5	.62	.06	.23	83.0	95.0	320.2	81.0	177	681	2,119
416	Utah No. 2 and R. I. No. 1	1	...do	7, 25, 06	10.02	40.55	.....do	29.37	79.0	.58	.20	.37	85.0	93.0	322.9	80.0	174	617	2,053
	Special tests:																		
500	Illinois	4	...do	1, 30, 07	9.02	40.55	Natural	29.72	76.5	.93	.22	....	38.0	48.0	321.0	38.0	155	784	2,555
501	.......do	4	...do	1, 31, 07	6.42	40.55	.....do	29.49	77.5	.64	.16	....	40.0	49.0	321.8	38.0	167	676	2,531
502	.......do	4	...do	2, 1, 07	8.82	40.55	.....do	29.27	73.0	.85	.12	....	44.0	55.0	318.3	38.0	168	698	2,158
503	.......do	4	...do	2, 2, 07	7.27	40.55	.....do	29.49	83.5	.91	.14	....	30.0	49.0	326.2	38.0	168	704	2,552
504	.......do	4	...do	2, 4, 07	6.37	40.55	.....do	29.57	74.0	.91	.19	....	17.0	43.0	319.2	38.0	161	725	2,484
505	.......do	4	...do	2, 5, 07	7.37	40.55	Forced	29.68	83.0	.99	.13	.25	15.0	43.0	325.9	38.0	140	761	2,755
517	.......do	4	...do	2, 28, 07	6.33	20.30	Natural	29.36	77.0	.50	.27	....	52.0	67.0	321.4	40.0	....	622	......
479	Washery refuse	4	...do	12, 18, 06	7.18	40.55	Forced	29.95	79.0	.92	.06	.73	33.0	44.0	322.9	44.0	178	577	......
519	Mixed coke	4	...do	3, 5, 07	8.92	40.55	.....do	29.65	77.5	.89	.07	.25	51.0	72.0	321.8	42.0	....	816	2,560

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel. Total weight of fuel consumed (pounds). As fired.	Fuel. Total weight of fuel consumed (pounds). Dry.	Fuel. Ash and refuse. Total (lbs.).	Fuel. Ash and refuse. Clinker (per cent).	Fuel. Total weight of combustible (pounds) determined from— Actual weight of ash.	Fuel. Total weight of combustible (pounds) determined from— Analyses of ash and coal.	Fuel. Ash and refuse in dry fuel (per cent).	Proximate analysis of fuel as fired (per cent). Moisture.	Proximate analysis of fuel as fired (per cent). Volatile.	Proximate analysis of fuel as fired (per cent). Fixed carbon.	Proximate analysis of fuel as fired (per cent). Ash.	Proximate analysis of fuel as fired (per cent). Sulphur (separately determined).	Ultimate analysis of dry fuel (per cent). Carbon.	Ultimate analysis of dry fuel (per cent). Hydrogen.	Ultimate analysis of dry fuel (per cent). Oxygen.	Ultimate analysis of dry fuel (per cent). Nitrogen.	Ultimate analysis of dry fuel (per cent). Sulphur.	Ultimate analysis of dry fuel (per cent). Ash.	Analyses of ash and refuse (per cent). Carbon.	Analyses of ash and refuse (per cent). Earthy matter.
1	2	32 (25)	33 (27)	34 (28)	35 (29)	36 (30)	37 (30)	38 (31)	39 (34)	40 (33)	41 (32)	42 (35)	43 (36)	44 (37)	45 (38)	46 (39)	47 (40)	48 (41)	49 (42)	50 (44)	51 (45)
17	Ala. No. 1	8 656	8,434	1,375	64	7,059	6,869	16.30	2.56	31.00	52.52	13.92	0.78	72.02	4.78	6.45	1.66	0.80	14.29	26.20	73.80
21	do	6,521	6,349	847	58	5,502	5,316	13.30	2.63	33.00	50.96	13.41	.94	72.65	4.71	6.49	1.42	.96	13.77	18.80	81.20
16	Ala. No. 2	9,198	8,754	1,201	61	7,553	7 328	13.80	4.83	32.98	48.65	13.54	1.17	69.83	4.54	8.60	1.57	1.23	14.23	15.10	84.90
382	Ala. No. 2B	9,919	9,542	1,317	53	8,225	8,025	13.80	3.80	32.09	50.47	13.64	1.19	69.71	4.35	8.95	1.57	1.24	14.18	12.48	87.52
383	do	7,308	7,019	1,093	49	5,926	5,804	15.57	3.95	30.70	50.76	14.59	1.12	68.94	4.30	8.85	1.55	1.17	15.19	13.66	86.34
410	do	7,600	7,339	891	0	6,448	6,217	12.14	3.43	32.74	51.34	12.49	1.24	72.17	4.77	7.27	1.58	1.28	12.93	19.39	80.61
390	Ala. No. 3	8,647	8,394	1,466	43	6,928	6,405	17.46	2.93	28.03	48.25	20.79	.55	66.28	4.03	6.62	1.08	.57	21.42	13.05	86.95
394	do	8,781	8,528	1,325	52	7,203	6,727	15.54	2.88	29.58	49.12	18.42	.58	68.34	4.15	6.83	1.11	.60	18.97	13.91	86.09
375	Ala. No. 4	8,993	8,630	921	54	7,709	7,463	10.67	4.04	30.27	55.21	10.48	1.29	76.16	4.98	5.30	1.30	1.34	10.92	24.34	75.66
376	do	7,236	6,886	962	44	5,924	5,631	13.97	4.84	28.17	52.70	14.29	1.22	72.67	4.75	5.04	1.24	1.28	15.02	23.00	77.00
377	do	7,928	7,477	1,110	49	6,367	5,831	14.85	5.69	26.94	49.48	17.89	1.05	69.36	4.54	4.83	1.19	1.11	18.97	20.58	79.42
378	do	5,467	5,179	715	54	4,464	4,305	13.81	5.27	28.72	52.78	13.23	.85	73.90	4.83	5.13	1.27	.90	13.97	21.14	78.86
413	do	8,665	8,452	744	47	7,708	7,592	8.80	2.46	32.27	56.55	8.72	1.18	76.96	4.72	6.85	1.32	1.21	8.94	13.95	86.05
478	Ala. No. 5	8,104	7,657	1,657	40	6,000	5,741	21.64	5.51	24.15	50.44	19.90	1.90	66.58	4.09	4.99	1.27	2.01	21.06	18.37	81.63
480	do	9,409	8,873	1,668	52	7,205	6,808	18.80	5.70	23.85	52.74	17.71	1.47	68.94	4.22	5.19	1.31	1.56	18.78	23.87	76.13
484	Ala. No. 6	8,063	7,852	717	44	7,135	7,084	9.13	2.86	25.80	63.98	7.36	.57	80.42	4.76	5.19	1.46	.59	7.58	24.14	75.86
9	Ark. No. 1	7,071	6,930	877	52	6,053	5,849	12.65	1.99	18.61	66.36	13.04	1.21	76.37	3.90	3.71	1.49	1.23	13.30	18.08	81.92
14	do	7,700	7,628	870	55	6,758	6,642	11.40	.94	21.21	67.65	10.20	1.73	79.76	3.91	2.70	1.58	1.75	10.30	23.02	76.98
8	Ark. No. 2	6,517	6,447	559	44	5,888	5,720	8.67	1.07	16.86	73.65	8.42	1.95	81.40	4.11	2.58	1.43	1.97	8.51	31.87	68.13
11	do	7,370	7,010	939	45	6,071	6,002	13.40	4.88	22.49	60.30	12.33	1.32	76.65	4.06	3.40	1.54	1.39	12.96	10.55	89.45
29	Ark. No. 3	8,158	7,997	1,011	52	6,986	6,815	12.64	1.97	16.04	72.74	9.25	1.29	79.17	4.12	4.35	1.60	1.32	9.44	42.19	57.81
35	do	8,600	8,376	1,488	54	6,888	6,615	17.76	2.60	17.35	62.04	18.01	1.41	72.47	3.46	2.72	1.42	1.44	18.49	14.27	85.73
40	Ark. No. 4	8,142	7,829	1,169	51	6,660	6,464	14.93	3.85	14.06	71.98	10.11	1.64	80.89	3.50	1.96	1.42	1.71	10.52	46.40	53.60
42	do	5,238	5,071	1,258	30	3,813	3,086	24.81	3.18	18.60	66.03	12.19	1.70	78.31	3.93	2.10	1.32	1.75	12.59	59.35	40.65
41	Ark. No. 5	9,000	8,800	1,956	52	6,844	6,938	22.23	2.22	12.54	73.68	11.56	2.39	78.43	3.66	2.27	1.42	2.45	11.77	42.05	57.95
293	Ark. No. 7A	5,764	5,451	816	52	4,635	4,092	14.97	5.41	16.10	68.34	10.15	1.81	78.49	4.03	3.48	1.36	1.91	10.73	21.46	78.54
294	do	7,440	7,027	816	57	6,211	6,004	11.61	5.55	15.88	67.40	11.17	1.86	77.47	3.97	3.42	1.34	1.97	11.83	23.59	76.41

297	Ark. No. 8	7,551	7,306	1,439	50	5,867	5,703	19.70	3.24	9.90	71.93	14.93	2.46	75.46	3.34	2.70	.53	2.54	15.43	33.09	66.91
308	.....do	3,500	3,292	609	36	2,683	2,726	18.50	5.93	11.21	74.80	8.06	2.08	82.06	3.63	2.96	.57	2.21	8.57	46.69	53.31
309	.....do	4,794	4,510	483	28	4,027	3,851	10.71	5.93	10.79	75.48	7.85	2.03	82.30	3.64	2.97	.59	2.16	8.34	58.32	41.68
340	Ark. No. 10	18,900	11,576	1,577	0	9,999	8,924	13.62	38.75	25.82	22.20	13.23	.57	55.88	4.00	16.55	1.04	.93	21.60	9.62	90.38
75	Colo. No. 1	8,972	7,197	1,028	23	6,174	6,071	14.21	19.78	35.85	39.00	5.37	.42	71.30	4.96	15.11	1.42	.52	6.69	62.94	37.06
386	Fla. No. 1	6,676	5,527	289	29	5,238	5,038	5.23	17.21	51.01	24.85	6.93	.49	57.77	5.18	25.20	2.89	.59	8.37	8.93	91.07
481	Ga. No. 1	8,847	8,572	1,675	65	6,897	6,736	19.54	3.11	16.90	62.77	17.22	1.29	70.99	3.92	4.90	1.09	1.33	17.77	18.65	81.35
18	Ill. No. 1	11,124	10,046	1,780	66	8,266	8,032	17.70	9.69	36.91	38.21	15.19	4.40	64.10	4.54	8.56	1.11	4.87	16.82	18.22	81.78
19	Ill. No. 2	10,096	9,041	980	55	8,111	7,843	10.40	10.45	37.77	41.72	10.06	3.36	69.39	5.12	9.50	1.01	3.75	11.23	19.57	80.43
33	Ill. No. 3	9,537	8,725	1,370	57	7,355	7,168	15.70	8.51	31.19	48.75	11.55	1.50	71.52	4.53	8.18	1.52	1.64	12.61	33.73	66.27
48	Ill. No. 4	9,367	8,105	1,171	64	6,934	6,837	14.44	13.47	33.48	41.59	11.46	1.28	69.90	4.59	9.48	1.31	1.48	13.24	16.61	83.38
50	.....do	10,759	9,398	1,209	67	8,099	7,924	13.82	12.58	32.44	43.63	11.35	1.36	70.02	4.60	9.51	1.33	1.56	12.99	19.56	80.44
73	Ill. No. 6	10,343	8,979	1,387	64	7,592	7,220	15.45	13.19	32.81	39.62	14.88	3.48	63.04	4.49	10.04	1.28	4.01	17.14	15.84	84.16
106	Ill. No. 6B	12,421	10,517	1,184	57	9,333	9,264	10.78	15.33	33.76	42.18	8.73	3.12	70.44	4.63	9.66	1.28	3.68	10.31	14.90	85.10
313	.....do	4,476	3,858	508	41	3,350	3,247	13.17	13.80	31.54	42.86	11.80	3.61	66.94	4.23	9.84	1.11	4.19	13.69	16.34	83.66
314	.....do	4,739	4,154	585	45	3,619	3,495	12.88	13.21	31.96	42.12	12.71	3.70	66.51	4.45	9.00	1.15	4.26	14.63	9.36	90.64
122	Ill. No. 7C	8,228	7,361	2,068	21	5,293	4,992	28.10	10.54	31.18	32.98	25.30	4.18	54.93	3.88	7.31	.92	4.67	28.29	13.85	86.15
129	.....do	8,085	6,755	789	39	5,966	5,913	11.68	16.45	34.43	40.18	8.94	3.22	70.00	4.95	9.33	1.16	3.86	10.70	15.14	84.86
142	Ill. No. 7D	9,100	8,155	1,325	51	6,830	6,541	16.25	10.38	34.33	39.08	16.21	4.28	63.24	4.49	8.33	1.07	4.78	18.09	10.48	89.52
143	.....do	8,471	7,599	1,257	52	6,342	5,903	16.55	10.29	32.34	38.95	18.42	4.66	60.90	4.31	8.02	1.04	5.20	20.58	10.81	89.19
146	.....do	8,264	7,413	1,397	47	6,016	5,600	18.84	10.29	32.16	38.35	19.20	5.01	59.86	4.24	7.91	1.01	5.58	21.40	16.27	83.73
516	Ill. No. 7E	11,900	10,178	2,756	66	7,422	7,184	27.08	14.47	28.14	35.16	22.23	3.73	56.08	3.84	8.82	.91	4.86	25.99	12.68	87.32
101	Ill. No. 8	12,141	10,525	1,697	35	8,828	8,442	16.12	13.31	34.61	39.39	12.69	5.16	65.13	4.59	8.58	1.16	5.95	14.64	31.91	68.09
102	.....do	13,168	11,500	1,575	59	9,925	9,550	13.70	12.67	34.23	40.00	13.10	4.68	65.31	4.61	8.56	1.16	5.36	15.00	14.30	85.70
103	Ill. No. 9A	12,359	10,782	1,297	59	9,485	9,327	12.03	12.76	36.12	40.78	10.34	3.94	68.45	4.92	9.16	1.16	4.52	11.85	13.64	86.36
104	.....do	10,619	9,322	1,182	56	8,140	7,942	12.68	12.21	36.38	40.27	11.14	3.89	67.83	4.88	9.08	1.09	4.43	12.69	16.67	83.33
105	.....do	14,000	12,306	1,260	60	11,046	10,655	10.24	12.10	36.23	41.05	10.62	4.08	68.17	4.89	9.13	1.10	4.64	12.07	13.17	86.83
113	.....do	10,890	9,294	934	44	8,360	8,253	10.05	14.66	36.71	41.19	7.44	3.34	71.54	5.13	9.55	1.15	3.91	8.72	24.72	75.28
121	Ill. No. 9B	10,760	9,609	1.238	48	8,371	8,149	12.90	10.70	35.84	41.82	11.64	4.11	67.42	4.83	8.99	1.12	4.60	13.04	16.75	83.25
492	Ill. No. 9C	10,691	9,128	1,367	51	7,761	7,595	14.98	14.62	32.38	39.13	13.87	3.51	65.67	4.83	8.77	.88	4.11	16.24	3.65	96.35
107	Ill. No. 10	9,800	8,661	1,228	55	7,433	7,227	14.18	11.62	30.59	44.93	12.86	1.45	68.93	4.59	8.86	1.43	1.64	14.55	14.25	85.75
108	.....do	9,940	9,017	1,177	59	7,840	7,671	13.06	9.29	31.24	47.84	11.63	1.44	70.38	4.69	9.06	1.46	1.59	12.82	16.18	83.82
109	.....do	8,695	7,798	1,253	44	6,545	6,304	16.07	10.32	30.01	46.27	13.40	1.46	68.61	4.57	8.83	1.42	1.63	14.94	26.29	73.71
110	.....do	8,244	7,478	1,219	43	6,259	6,237	16.30	9.29	32.54	48.11	10.06	1.40	71.87	4.78	9.23	1.49	1.54	11.09	33.77	66.23
114	.....do	10,031	8,860	773	36	8,087	8,040	8.72	11.67	32.37	49.87	6.09	1.22	75.42	5.03	9.67	1.61	1.38	6.89	27.20	72.80
137	Ill. No. 11A	8,312	7,660	1,077	42	6,583	6,332	14.07	7.84	28.08	51.54	12.54	2.35	70.06	4.50	7.89	1.39	2.55	13.61	26.51	73.49
138	.....do	7,889	7,285	1,051	40	6,234	5,981	14.43	7.66	29.76	48.65	13.93	2.16	69.00	4.43	7.76	1.38	2.34	15.09	19.46	80.54
139	.....do	7,700	7,119	1,019	40	6,100	5,927	14.31	7.54	30.09	49.31	13.06	2.57	69.44	4.46	7.83	1.37	2.78	14.12	18.40	81.60
141	.....do	5,849	5,402	586	50	4,816	4,618	10.85	7.65	30.06	50.50	11.79	2.09	70.99	4.56	8.01	1.41	2.26	12.77	16.02	83.98
111	Ill. No. 11B	9,731	8,936	1,454	40	7,482	7,294	16.27	8.17	31.53	48.21	12.09	2.82	70.54	4.57	7.20	1.46	3.07	13.16	32.05	67.95
112	.....do	9,001	8,197	1,522	32	6,675	6,593	18.57	8.93	30.73	48.21	12.13	2.33	70.22	4.65	7.84	1.41	2.56	13.32	33.65	66.35
115	.....do	10,051	9,161	1,352	56	7,809	7,455	14.76	8.85	28.12	48.08	14.95	2.24	67.72	4.49	7.57	1.36	2.46	16.40	15.09	84.91
116	.....do	6,403	5,936	788	60	5,148	5,052	13.27	7.29	31.34	50.07	11.30	2.50	71.07	4.70	7.92	1.42	2.70	12.19	20.36	79.64
117	.....do	10,447	9,748	1,322	58	8,426	8,237	13.56	6.69	32.95	47.59	12.77	3.47	69.56	4.52	7.08	1.44	3.72	13.68	13.42	86.58
118	.....do	9,904	9,294	1,269	56	8,025	7,895	13.65	6.16	33.21	48.91	11.72	3.14	70.90	4.60	7.20	1.46	3.35	12.49	18.75	81.25
119	.....do	11,200	10,480	1,231	55	9,249	9,056	11.75	6.43	32.23	50.58	10.76	2.22	71.96	4.77	7.95	1.44	2.37	11.51	17.71	82.29
120	Ill. No. 11C	10,135	9,209	976	42	8,233	8,212	10.60	9.14	31.03	52.33	7.50	1.64	74.65	4.85	8.98	1.47	1.80	8.25	24.30	75.70
312	.....do	3,145	2,845	302	45	2,543	2,546	10.62	9.54	31.60	50.92	7.94	1.92	74.80	4.72	8.41	1.18	2.11	8.78	16.06	83.94
127	Ill. No. 12	9,554	8,743	1,349	56	7,394	7,114	15.43	8.49	31.04	45.25	15.22	3.79	65.71	4.39	7.97	1.16	4.14	16.63	12.95	87.05
128	.....do	9,496	8,743	1,171	60	7,572	7,275	13.39	7.93	31.85	46.18	14.04	3.92	66.76	4.45	8.11	1.17	4.26	15.25	11.54	88.46
131	.....do	8,400	7,599	1,467	41	6,132	5,797	19.28	9.54	29.52	43.97	16.97	4.18	63.55	4.24	7.71	1.12	4.62	18.76	25.57	74.43
133	.....do	9,176	8,369	1,478	41	6,891	6,600	17.66	8.79	30.70	44.90	15.61	4.14	65.00	4.33	7.87	1.14	4.54	17.12	22.75	77.25
135	.....do	9,384	8,428	1,001	40	7,427	7,380	11.88	10.19	33.30	47.27	9.24	2.58	72.02	4.82	8.73	1.27	2.87	10.29	18.12	81.88

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel. Total weight of fuel consumed (pounds). As fired.	Fuel. Total weight of fuel consumed (pounds). Dry.	Fuel. Ash and refuse. Total (lbs.).	Fuel. Ash and refuse. Clinker (per cent).	Fuel. Total weight of combustible (pounds) determined from— Actual weight of ash.	Fuel. Total weight of combustible (pounds) determined from— Analyses of ash and coal.	Fuel. Ash and refuse in dry fuel (per cent).	Proximate analysis of fuel as fired (per cent). Moisture.	Proximate analysis of fuel as fired (per cent). Volatile.	Proximate analysis of fuel as fired (per cent). Fixed carbon.	Proximate analysis of fuel as fired (per cent). Ash.	Proximate analysis of fuel as fired (per cent). Sulphur (separately determined).	Ultimate analysis of dry fuel (per cent). Carbon.	Ultimate analysis of dry fuel (per cent). Hydrogen.	Ultimate analysis of dry fuel (per cent). Oxygen.	Ultimate analysis of dry fuel (per cent). Nitrogen.	Ultimate analysis of dry fuel (per cent). Sulphur.	Ultimate analysis of dry fuel (per cent). Ash.	Analyses of ash and refuse (per cent). Carbon.	Analyses of ash and refuse (per cent). Earthy matter.
1	2	32 (25)	33 (27)	34 (28)	35 (29)	36 (30)	37 (30)	38 (31)	39 (34)	40 (33)	41 (32)	42 (35)	43 (36)	44 (37)	45 (38)	46 (39)	47 (40)	48 (41)	49 (42)	50 (44)	51 (45)
136	Ill. No. 12	8,164	7,316	1,360	36	5,956	5,788	18.59	10.39	29.39	44.64	15.58	3.56	65.23	4.36	7.91	1.15	3.97	17.38	18.80	81.20
463	Ill. No. 12B	8,166	7,595	951	41	6,644	6,625	12.52	6.99	32.36	50.24	10.41	2.41	72.03	4.49	8.61	1.09	2.59	11.19	12.65	87.35
132	Ill. No. 13	8,905	8,019	1,192	41	6,827	6,724	14.86	9.95	30.22	47.73	12.10	1.32	70.32	4.55	8.64	1.58	1.47	13.44	18.17	81.83
134	do	9,100	8,223	1,133	44	7,090	7,015	13.78	9.64	30.50	48.81	11.05	1.59	71.07	4.60	8.75	1.59	1.76	12.23	17.87	82.13
144	do	8,206	7,412	790	47	6,622	6,673	10.66	9.67	32.59	50.18	7.56	1.30	74.52	4.83	9.17	1.67	1.44	8.37	15.03	84.97
145	do	6,255	5,591	473	45	5,118	5,051	8.46	10.60	31.38	50.84	7.18	1.34	74.77	4.84	9.18	1.68	1.50	8.08	19.16	80.84
123	Ill. No. 14	9,672	8,545	1,274	37	7,271	6,982	14.91	11.65	34.67	40.12	13.56	4.62	65.44	4.53	8.24	1.22	5.23	15.34	19.77	80.23
125	do	9,313	8,139	1,165	49	6,974	6,817	14.30	12.61	33.60	41.30	12.49	4.18	66.72	4.62	8.38	1.25	4.74	14.29	13.69	86.31
130	do	10,331	8,696	1,028	45	7,668	7,569	11.82	15.83	33.50	41.38	9.29	3.24	70.11	4.86	8.83	1.31	3.85	11.04	16.29	83.71
126	Ill. No. 15	9,100	8,190	1,334	....	6,856	6,575	16.29	10.00	33.39	41.20	15.41	4.36	63.78	4.43	8.70	1.12	4.85	17.12	15.97	84.03
152	do	9,050	7,981	906	55	7,075	7,108	11.35	11.81	37.09	42.69	8.41	3.00	71.17	4.94	9.71	1.24	3.40	9.54	12.30	87.70
150	Ill. No. 16	6,600	5,995	637	49	5,358	5,222	10.62	9.16	29.57	51.04	10.23	1.76	72.31	4.56	8.33	1.60	1.94	11.26	15.37	84.63
140	Ill. No. 18	7,641	6,745	818	32	5,927	5,861	12.13	11.72	37.27	41.73	9.28	4.07	69.57	5.09	9.09	1.13	4.61	10.51	21.37	78.63
148	do	8,604	7,649	886	44	6,763	6,658	11.58	11.10	37.11	42.14	9.65	3.37	69.97	5.11	9.14	1.14	3.79	10.85	18.14	81.86
147	do	8,321	7,074	738	29	6,336	6,390	10.43	14.99	37.24	42.00	5.77	2.98	73.53	5.36	9.61	1.20	3.51	6.79	27.70	72.30
149	do	4,617	3,849	446	48	3,403	3,525	11.59	16.64	36.13	41.51	5.72	2.72	73.68	5.37	9.63	1.20	3.26	6.86	13.42	86.58
160	Ill. No. 19A	8,606	7,505	765	58	6,740	6,618	10.19	12.79	27.24	51.73	8.24	.49	74.67	4.47	9.24	1.61	.56	9.45	23.27	76.73
161	do	8,300	7,185	896	58	6,289	6,222	12.47	13.43	27.60	50.08	8.89	.50	73.99	4.44	9.16	1.58	.58	10.25	25.10	74.90
163	do	9,657	8,415	847	54	7,568	7,469	10.06	12.86	28.30	50.80	8.04	.51	74.33	4.49	9.25	1.61	.59	9.23	19.95	80.05
170	do	7,700	6,677	822	42	5,855	5,804	12.31	13.28	27.72	49.75	9.25	.50	73.65	4.42	9.10	1.58	.58	10.67	19.63	80.37
171	do	8,400	7,292	876	45	6,416	6,355	12.08	13.19	27.56	50.33	8.92	.50	73.97	4.44	9.14	1.59	.58	10.28	21.43	78.57
175	Ill. No. 19B	9,241	8,250	1,076	10	7,174	7,133	13.04	10.72	29.77	49.30	10.21	.47	74.37	4.59	7.52	1.56	.53	11.43	16.21	83.79
204	do	8,351	7,553	703	48	6,850	6,586	9.31	9.56	29.40	51.11	9.93	.61	74.62	4.60	7.56	1.57	.67	10.98	19.53	80.47
205	do	8,209	7,363	809	41	6,554	6,302	10.99	10.30	29.20	50.27	10.23	.55	74.33	4.58	7.51	1.56	.61	11.41	27.40	72.60
420	Ill. No. 19C	8,894	8,118	1,007	57	7,111	6,819	12.40	8.72	28.41	50.58	12.29	.63	71.08	4.64	8.57	1.56	.69	13.46	20.48	79.52
423	do	7,612	6,805	917	51	5,978	5,812	13.30	9.42	28.05	50.72	11.81	.61	71.44	4.07	8.01	1.57	.67	13.04	20.02	79.98

424	Ill. No. 19D......	8,271	7,572	947	54	6,627	6,457	12.51	8.45	29.65	50.24	11.66	.58	70.23	4.12	10.74	1.59	.58	12.74	15.95	84.05
425	.....do...........	8,565	7,836	967	59	6,869	6,684	12.34	8.51	30.27	49.85	11.37	.51	70.51	4.13	10.77	1.60	.56	12.43	18.38	81.62
421	Ill. No. 19E......	8,689	7,888	967	58	6,921	6,737	12.20	9.22	29.28	50.25	11.25	.59	70.47	4.13	10.76	1.60	.65	12.39	17.84	82.16
422	.....do...........	8,801	7,943	931	63	7,012	6,796	11.72	9.75	28.45	50.67	11.13	.61	71.48	4.13	9.80	1.58	.68	12.33	17.91	82.09
292	Ill. No. 20.......	7,197	6,152	1,196	55	4,956	4,901	19.44	14.52	31.98	38.01	15.49	4.32	62.59	4.28	8.82	1.14	5.05	18.12	11.37	88.63
301	.....do...........	10,670	8,908	955	45	7,953	7,590	10.72	16.51	32.17	40.87	10.45	3.25	68.11	4.66	9.60	1.23	3.89	12.51	21.23	78.77
302	.....do...........	10,089	8,438	832	51	7,606	7,289	9.86	16.36	33.54	39.84	10.26	3.22	68.34	4.68	9.63	1.23	3.85	12.27	13.74	86.26
315	Ill. No. 21.......	4,666	3,968	487	56	3,481	3,256	12.27	14.95	30.33	40.96	13.76	1.60	65.89	4.39	10.43	1.23	1.88	16.80	14.38	85.62
316	.....do...........	9,602	8,155	1,029	62	7,126	6,809	12.62	15.07	30.78	41.90	12.25	1.27	67.62	4.50	10.69	1.27	1.50	14.42	16.51	83.49
318	.....do...........	9,060	7,492	942	47	6,550	6,488	12.57	17.31	30.40	42.28	10.01	1.28	70.01	4.41	10.61	1.32	1.55	12.10	10.33	89.67
324	Ill. No. 22A......	10,500	9,292	1,322	60	7,970	7,477	14.23	11.50	33.44	39.27	15.79	6.24	61.77	4.18	8.09	1.07	7.05	17.84	11.90	88.10
325	.....do...........	10,250	9,171	1,213	60	7,958	7,612	13.23	10.53	35.63	40.04	13.80	6.07	63.97	4.33	8.37	1.12	6.78	15.43	11.89	88.11
328	.....do...........	12,526	10,729	1,179	53	9,550	9,534	10.99	14.35	36.86	40.57	8.22	3.75	70.73	4.79	9.27	1.23	4.38	9.60	14.01	85.99
306	Ill. No. 23A......	8,246	7,051	941	66	6,110	5,818	13.35	14.49	32.37	39.69	13.45	4.62	64.36	4.62	8.87	1.02	5.40	15.73	13.21	86.79
317	.....do...........	7,576	6,467	665	50	5,802	5,715	10.28	14.64	35.72	40.76	8.88	3.23	70.04	5.03	9.65	1.10	3.78	10.40	11.84	88.16
321	Ill. No. 23B......	4,900	4,237	411	62	3,826	3,788	9.70	13.54	36.38	41.67	8.41	3.21	69.30	4.86	11.26	1.14	3.71	9.73	8.75	91.25
322	.....do...........	4,200	3,631	352	62	3,279	3,247	9.69	13.54	36.38	41.67	8.41	3.21	69.30	4.86	11.26	1.14	3.71	9.73	8.75	91.25
335	Ill. No. 24B......	9,100	7,995	1,035	60	6,960	6,794	12.95	12.14	33.71	42.48	11.67	4.53	67.18	4.61	8.63	1.14	5.16	13.28	13.45	86.55
336	.....do...........	6,030	5,270	827	59	4,443	4,507	15.69	12.60	34.40	43.13	9.87	3.83	69.47	4.77	8.91	1.18	4.38	11.29	20.37	79.63
337	.....do...........	4,299	3,718	620	58	3,098	3,193	16.67	13.52	32.84	43.17	10.47	3.97	68.61	4.71	8.81	1.17	4.59	12.11	12.07	87.93
338	Ill. Nos. 25A and 25B............	9,549	8,376	1,410	63	6,966	7,022	16.83	12.28	35.52	40.53	11.67	3.57	67.23	4.87	9.30	1.23	4.07	13.30	17.03	82.97
339	.....do...........	10,826	9,578	1,531	65	8,047	7,815	15.98	11.53	34.93	39.75	13.79	4.89	64.20	4.65	8.85	1.18	5.53	15.59	17.61	82.39
341	Ill. No. 26.......	8,806	7,613	1,270	32	6,343	6,214	16.68	13.55	33.11	40.24	13.10	4.45	65.81	4.43	8.23	1.23	5.15	15.15	19.31	80.69
342	.....do...........	8,811	7,429	1,310	37	6,119	6,135	17.63	15.68	32.41	39.82	12.09	3.51	67.31	4.53	8.40	1.26	4.16	14.34	17.49	82.51
353	Ill. No. 27.......	9,573	8,041	1,099	67	6,942	6,601	13.67	16.00	32.41	37.82	13.77	4.05	64.15	4.49	9.07	1.08	4.82	16.39	11.12	88.88
354	.....do...........	9,293	7,823	1,169	65	6,654	6,368	14.94	15.82	32.50	37.73	13.95	4.80	63.29	4.43	8.94	1.07	5.70	16.57	13.54	86.46
459	Ill. No. 28A......	8,151	7,554	989	43	6,565	6,452	13.09	7.32	30.72	49.84	12.12	1.29	71.88	4.21	7.85	1.59	1.39	13.08	11.52	88.48
457	Ill. No. 28B......	7,800	7,347	954	36	6,393	6,273	12.98	5.81	30.86	52.41	10.92	2.03	71.92	4.60	8.36	1.37	2.16	11.59	23.28	76.72
448	Ill. No. 28C......	9,622	9,158	1,087	44	8,071	7,911	11.87	4.82	30.81	53.82	10.55	1.47	72.85	4.54	8.68	1.30	1.54	11.09	21.31	78.69
452	.....do...........	9,587	8,914	1,067	40	7,847	7,726	11.97	7.02	29.93	53.51	9.54	1.18	73.75	4.59	8.81	1.32	1.27	10.26	25.61	74.39
465	Ill. No. 29A......	9,600	8,234	847	42	7,387	7,424	10.29	14.23	34.63	43.96	7.18	2.84	72.39	4.78	10.07	1.08	3.31	8.37	14.23	85.77
460	Ill. No. 29B......	9,800	8,713	1,301	49	7,412	7,100	14.93	11.09	33.68	41.17	14.06	4.63	63.96	4.45	9.46	1.11	5.21	15.81	18.07	81.93
461	.....do...........	5,600	4,905	491	64	4,414	4,270	10.01	12.41	35.42	42.15	10.02	3.51	68.47	4.77	10.11	1.20	4.01	11.44	15.12	84.88
466	.....do...........	10,131	9,118	1,050	38	8,068	7,948	11.52	10.00	36.33	43.01	10.66	3.24	69.45	4.82	9.03	1.26	3.60	11.84	8.56	91.44
511	Ill. No. 30.......	8,070	7,283	661	40	6,622	6,528	9.08	9.75	39.25	42.69	8.31	3.21	71.70	4.80	9.60	1.13	3.56	9.21	12.92	87.08
489	Ill. No. 31.......	9,500	8,121	1,189	45	6,932	6,836	14.64	14.52	33.74	39.40	12.34	3.36	67.91	4.68	7.92	1.12	3.93	14.44	9.42	90.58
491	.....do...........	9,600	8,562	1,317	47	7,245	7,224	15.38	10.81	32.72	42.74	12.73	3.50	67.31	4.54	8.92	1.04	3.93	14.27	8.79	91.21
513	Ill. No. 33.......	10,500	9,293	2,433	52	6,860	6,686	26.18	11.50	25.44	42.37	20.69	1.52	61.46	3.72	8.70	1.02	1.72	23.38	17.84	82.16
509	Ill. No. 34B......	8,400	7,849	814	49	7,035	7,074	10.37	6.56	34.15	51.57	7.72	2.17	74.00	4.87	8.98	1.58	2.31	8.26	15.48	84.52
71	Ind. No. 1.......	6,579	5,807	447	47	5,360	5,353	7.69	11.74	38.79	43.23	6.24	2.03	75.77	4.91	8.48	1.47	2.30	7.07	20.41	79.59
68	.....do...........	10,819	9,024	807	45	8,217	8,013	8.94	16.59	35.17	40.41	7.83	2.18	73.02	4.97	8.58	1.43	2.61	9.89	20.35	79.65
65	Ind. No. 2.......	9,274	8,429	1,015	49	7,414	7,099	12.02	9.11	38.04	40.40	12.45	4.12	68.08	4.78	7.56	1.35	4.53	13.70	17.24	82.76
162	Ind. No. 3.......	8,959	7,846	1,295	53	6,551	6,269	16.51	12.42	31.83	40.68	15.07	4.84	63.44	4.53	8.03	1.26	5.53	17.21	17.50	82.50
151	Ind. No. 4.......	8,856	7,595	1,245	58	6,350	6,148	16.40	14.24	31.59	39.96	14.21	2.52	66.31	4.42	8.46	1.30	2.94	16.57	15.07	84.93
165	.....do..........	9,314	8,027	1,343	53	6,684	6,198	16.73	13.82	29.12	39.80	17.26	2.43	63.59	4.24	8.09	1.23	2.82	20.03	16.44	83.56
166	.....do...........	7,379	6,288	1,330	44	4,958	4,830	21.15	14.79	29.76	39.69	15.76	2.52	64.73	4.31	8.25	1.26	2.96	18.49	22.18	77.82
154	.....do...........	9,100	7,753	676	44	7,077	6,970	8.73	14.80	33.10	44.91	7.19	2.12	73.41	4.89	9.35	1.42	2.49	8.44	19.01	80.99
153	Ind. No. 5.......	8,803	7,807	946	57	6,861	6,687	12.11	11.31	36.36	41.29	11.04	5.07	68.25	4.68	7.68	1.22	5.72	12.45	15.70	84.30
155	.....do...........	7,987	7,042	894	53	6,148	5,933	12.69	11.83	34.23	42.27	11.67	4.65	67.95	4.66	7.66	1.21	5.29	13.23	19.79	80.21
156	.....do...........	8,649	7,697	986	55	6,711	6,591	12.81	11.01	35.02	43.01	10.96	4.35	69.06	4.73	7.79	1.22	4.89	12.31	15.98	84.02
157	Ind. No. 6.......	8,400	7,517	1,109	53	6,408	6,311	14.75	10.51	34.80	41.93	12.76	4.55	68.03	4.76	6.61	1.26	5.08	14.26	12.05	87.95
159	.....do...........	9,710	8,616	866	51	7,750	7,571	10.05	11.27	37.90	41.20	9.63	3.57	71.77	5.02	7.01	1.33	4.02	10.85	12.66	87.34

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel. Total weight of fuel consumed (pounds). As fired.	Fuel. Total weight of fuel consumed (pounds). Dry.	Fuel. Ash and refuse. Total (lbs.).	Fuel. Ash and refuse. Clinker (per cent).	Fuel. Total weight of combustible (pounds) determined from— Actual weight of ash.	Fuel. Total weight of combustible (pounds) determined from— Analyses of ash and coal.	Fuel. Ash and refuse in dry fuel (per cent).	Proximate analysis of fuel as fired (per cent). Moisture.	Proximate analysis of fuel as fired (per cent). Volatile.	Proximate analysis of fuel as fired (per cent). Fixed carbon.	Proximate analysis of fuel as fired (per cent). Ash.	Proximate analysis of fuel as fired (per cent). Sulphur (separately determined).	Ultimate analysis of dry fuel (per cent). Carbon.	Ultimate analysis of dry fuel (per cent). Hydrogen.	Ultimate analysis of dry fuel (per cent). Oxygen.	Ultimate analysis of dry fuel (per cent). Nitrogen.	Ultimate analysis of dry fuel (per cent). Sulphur.	Ultimate analysis of dry fuel (per cent). Ash.	Analyses of ash and refuse (per cent). Carbon.	Analyses of ash and refuse (per cent). Earthy matter.
1	2	32 (25)	33 (27)	34 (28)	35 (29)	36 (30)	37 (30)	38 (31)	39 (34)	40 (33)	41 (32)	42 (35)	43 (36)	44 (37)	45 (38)	46 (39)	47 (40)	48 (41)	49 (42)	50 (44)	51 (45)
158	Ind. No. 7A	8,847	8,068	808	54	7,260	7,156	10.01	8.81	38.98	43.34	8.84	3.67	72.37	5.10	7.49	1.33	4.02	9.69	16.07	83.93
288	do	7,700	6,881	733	37	6,148	5,964	10.65	10.64	34.12	45.52	9.72	3.57	71.34	4.95	7.60	1.23	4.00	10.88	22.87	77.13
164	Ind. No. 7B	7,771	6,936	855	43	6,081	6,000	12.33	10.74	37.78	41.27	10.21	3.92	70.01	4.88	8.03	1.25	4.39	11.44	16.78	83.22
176	do	7,881	7,143	792	42	6,351	6,153	11.09	9.37	38.40	41.18	11.05	4.17	69.21	4.82	7.94	1.24	4.60	12.19	15.00	85.00
182	Ind. No. 8	8,830	8,003	900	56	7,103	6,846	11.25	9.37	36.93	42.33	11.37	4.05	69.86	4.83	7.11	1.18	4.47	12.55	17.00	83.00
183	do	7,815	6,991	863	50	6,128	5,931	12.34	10.54	35.48	41.46	12.52	4.22	68.42	4.73	6.98	1.15	4.72	14.00	9.48	90.52
185	do	8,857	7,961	1,047	54	6,914	6,701	13.15	10.12	35.55	41.44	12.89	3.54	68.80	4.76	7.00	1.16	3.94	14.34	11.26	88.74
184	do	9,100	8,020	858	50	7,162	7,069	10.70	11.87	37.17	41.67	9.29	2.87	72.57	5.01	7.39	1.23	3.26	10.54	12.34	87.66
168	Ind. No. 9A	9,800	8,625	1,172	52	7,453	7,170	13.59	11.99	34.76	39.88	13.37	3.82	66.85	4.64	7.86	1.12	4.34	15.19	12.36	87.64
169	do	8,806	7,703	1,050	49	6,653	6,527	13.63	12.53	34.80	40.73	11.94	3.52	68.40	4.74	8.03	1.16	4.02	13.65	11.89	88.11
174	Ind. No. 9B	5,895	5,210	627	41	4,583	4,495	12.03	11.62	36.33	41.33	10.72	2.95	69.48	4.98	8.84	1.23	3.34	12.13	13.22	86.78
334	Ind. Nos. 9A and 9B	4,341	3,795	448	52	3,347	3,306	11.81	12.57	35.24	42.16	10.03	3.15	70.28	4.64	8.76	1.25	3.60	11.47	12.15	87.85
167	Ind. No. 10	9,354	8,362	952	49	7,410	7,231	11.38	10.60	37.90	41.34	10.16	4.21	69.32	5.10	8.26	1.26	4.72	11.36	18.97	81.03
177	do	10,500	9,347	626	51	8,721	8,585	6.70	10.98	41.13	41.65	6.24	3.50	73.54	5.40	8.78	1.34	3.93	7.01	17.05	82.95
233	Ind. No. 11	9,100	8,014	845	52	7,169	7,179	10.54	11.93	33.01	47.16	7.90	1.50	74.07	4.69	8.99	1.58	1.70	8.97	13.74	86.26
234	do	7,974	7,085	659	44	6,426	6,330	9.30	11.15	33.18	47.23	8.44	1.58	73.55	4.66	8.95	1.56	1.78	9.50	12.48	87.52
235	do	8,735	7,675	632	48	7,043	6,930	8.23	12.14	31.29	48.83	7.74	1.28	74.38	4.71	9.06	1.58	1.46	8.81	10.72	89.28
299	Ind. No. 12	9,681	8,441	1,256	....	7,185	6,947	14.88	12.81	33.48	39.63	14.08	3.84	65.66	4.54	7.99	1.20	4.40	16.15	10.45	89.55
300	do	10.500	9,197	1,282	30	7,915	7,549	13.94	12.41	34.12	39.61	13.86	4.21	65.61	4.54	7.96	1.26	4.81	15.82	15.08	84.92
310	do	8,400	7,319	820	26	6,499	6,527	11.20	12.87	35.85	43.34	7.94	3.02	72.27	5.00	8.76	1.39	3.47	9.11	15.22	84.78
432	Ind. No. 13	9,328	8,135	1,139	53	6,996	6,835	14.00	12.79	35.45	39.67	12.09	3.18	68.61	4.77	8.17	.94	3.05	13.86	15.07	84.93
433	do	3,610	3,120	564	52	2,556	2,581	18.08	13.56	33.93	40.81	11.68	2.92	69.13	4.80	8.22	.95	3.38	13.52	20.81	79.19
430	Ind. No. 14	8,304	7,596	1,222	61	6,374	6,225	16.09	8.52	35.99	41.10	14.39	5.62	64.18	4.66	8.32	1.00	6.14	15.73	14.47	85.53
431	do	8,640	7,829	1,322	55	6,507	5,882	16.89	9.30	33.58	36.89	20.14	5.47	58.90	4.28	7.63	.92	6.04	22.23	15.63	84.37
428	Ind. No. 15	9,100	7,912	850	53	7,062	6,920	10.74	13.05	31.34	46.78	8.83	.99	72.85	4.75	9.47	1.63	1.14	10.16	22.19	77.81
429	do	8,545	7.449	794	41	6,655	6,574	10.66	12.83	32.49	46.45	8.23	.97	73.45	4.78	9.58	1.64	1.11	9.44	21.56	78.44

426	Ind. No. 16......	8,618	7,835	1,029	53	6,806	6,584	13.18	9.09	35.20	43.21	12.50	4.77	67.02	4.66	8.15	1.17	5.25	13.75	16.83	83.17
427	.....do...........	7,000	6,294	857	50	5,437	5,274	13.62	10.09	33.62	43.51	12.78	4.34	66.99	4.66	8.14	1.17	4.83	14.21	14.55	85.45
441	Ind. No. 17......	8,097	7,853	1,032	38	6,821	6,811	13.14	9.70	35.78	45.68	8.89	3.67	71.05	4.70	9.30	1.04	4.06	9.85	26.03	73.97
442	.....do...........	8,400	7,385	1,214	33	6,171	6,139	16.44	12.08	32.48	44.42	11.02	3.65	68.75	4.55	9.00	1.01	4.15	12.54	26.44	73.56
435	Ind. No. 18B....	9,532	8,384	836	32	7,546	7,520	10.00	12.04	34.09	46.84	7.08	1.65	74.23	4.92	9.69	1.30	1.88	7.90	22.08	77.92
436	.....do...........	9,744	8,566	882	29	7,684	7,647	10.30	12.09	34.10	47.08	6.78	1.37	74.72	4.96	9.75	1.30	1.56	7.71	29.25	70.75
464	Ind. No. 19......	7,048	6,408	828	33	5,580	5,286	12.85	9.09	34.61	40.70	15.60	3.04	63.67	4.34	10.36	1.13	3.34	17.16	8.26	91.74
10	Ind. T. No. 1....	8,210	7,582	1,104	48	6,479	6,284	14.50	7.65	33.96	46.30	12.09	1.80	70.82	4.79	8.04	1.31	1.95	13.09	32.23	67.77
20	Ind. T. No. 2....	9,213	8,871	1,073	60	7,798	7,746	12.10	3.71	36.21	50.31	9.77	1.39	74.00	4.97	7.66	1.78	1.44	10.15	20.96	79.04
417	Ind. T. No. 2B..	7,547	7,330	935	44	6,395	6,271	12.76	2.88	35.40	51.87	9.85	1.80	74.63	4.89	6.61	1.88	1.85	10.14	33.64	66.36
418	.....do...........	7,596	7,374	840	48	6,534	6,493	11.39	2.92	36.14	52.42	8.52	1.98	75.63	4.94	6.70	1.91	2.04	8.78	27.82	72.18
455	.....do...........	8,231	8,009	961	26	7,048	7,059	12.00	2.70	35.84	53.40	8.06	1.46	76.57	4.95	6.91	1.79	1.50	8.28	29.72	70.28
453	.....do...........	8,400	8,124	974	34	7,150	7,089	11.99	3.29	35.25	53.15	8.31	1.52	76.11	4.93	7.11	1.69	1.57	8.59	34.59	65.41
456	.....do...........	9,000	8,744	871	32	7,873	7,781	9.96	2.85	34.91	54.03	8.21	1.50	76.28	4.87	7.15	1.71	1.54	8.45	25.71	74.29
32	Ind. T. No. 3....	9,145	8,707	1,376	62	7,331	7,454	15.80	4.79	37.30	47.58	10.33	3.93	71.03	4.65	7.77	1.57	4.13	10.85	22.40	77.60
52	Ind. T. No. 4....	9,296	8,716	1,041	50	7,675	7,342	11.94	6.24	35.44	45.33	12.99	3.86	66.76	4.53	9.28	1.46	4.12	13.85	15.94	84.06
437	Ind. T. No. 8....	6,000	5,832	762	27	5,070	5,141	13.07	2.80	35.67	53.77	7.76	1.58	75.63	4.91	8.33	1.52	1.63	7.98	29.56	70.44
449	Ind. T. No. 9....	7,861	7,561	933	26	6,628	6,629	12.34	3.81	13.62	76.16	6.41	1.17	84.26	4.39	1.75	1.72	1.22	6.66	46.03	53.97
450	.....do...........	7,726	7,464	....	....	....	6,649	....	3.39	17.15	72.04	7.42	1.15	82.89	4.23	2.40	1.61	1.19	7.68	28.59	71.41
45	Iowa No. 1......	10,331	9,433	1,875	63	7,558	7,292	19.88	8.69	33.08	39.89	18.34	6.39	61.67	4.01	6.26	.97	7.00	20.09	13.12	86.88
67	Iowa No. 2......	10,986	9,351	1,629	58	7,722	7,294	17.44	14.88	35.35	33.73	16.04	4.73	62.04	4.49	7.59	1.50	5.56	18.82	18.07	81.93
49	Iowa No. 3......	10,668	9,341	1,431	57	7,910	7,283	15.32	12.44	36.14	35.77	15.65	6.07	62.34	4.56	7.34	.96	6.93	17.87	27.11	72.89
47	Iowa No. 4......	9,385	8,120	1,302	59	6,818	6,447	16.03	13.48	34.09	37.28	15.15	5.04	63.43	4.35	7.92	.97	5.82	17.51	19.25	80.75
66	.....do...........	9,900	8,589	1,186	58	7,403	7,078	13.82	13.24	36.50	37.85	12.41	3.90	69.25	4.81	6.28	.86	4.49	14.81	23.82	76.18
55	Iowa No. 5......	11,200	9,407	1,328	57	8,079	7,700	14.12	16.01	31.76	38.83	13.40	3.09	65.21	4.71	9.12	1.33	3.68	15.95	15.49	84.51
601	Jamestown No. 1.	5,955	5,876	858	....	5,018	4,855	14.60	1.33	28.69	54.26	15.72	.94	71.14	4.52	6.21	1.25	.95	15.93	9.93	90.07
602	.....do...........	7,299	7,184	975	57	6,209	5,862	13.57	1.58	28.67	53.15	16.60	.94	70.59	4.47	5.69	1.22	1.16	16.87	11.26	88.74
603	Jamestown No. 3.	7,281	7,141	440	....	6,701	6,468	6.16	1.92	15.41	74.65	8.02	.68	82.90	4.65	2.30	1.28	.69	8.18	20.32	79.68
604	.....do...........	7,500	7,366	429	....	6,937	6,605	5.82	1.79	14.95	74.20	9.06	.98	81.67	4.57	2.27	1.26	1.00	9.23	18.98	81.02
605	.....do...........	6,838	6,705	455	....	6,250	6,062	6.79	1.95	14.95	74.27	8.83	.69	82.14	4.61	2.27	1.27	.70	9.01	8.59	91.41
606	.....do...........	5,117	5,003	438	58	4,565	4,542	8.76	2.23	15.30	75.87	6.60	.62	84.36	4.48	2.63	1.15	.63	6.75	28.02	71.98
607	.....do...........	5,181	5,070	432	57	4,638	4,688	8.52	2.15	15.30	77.54	5.01	.68	85.79	4.56	2.67	1.17	.69	5.12	28.26	71.74
608	Jamestown No. 4.	5,541	5,421	320	61	5,101	5,031	5.90	2.17	18.92	73.99	4.92	1.05	84.38	4.77	3.20	1.55	1.07	5.03	36.44	63.56
609	.....do...........	4,781	4,677	381	....	....	4,332	....	2.18	17.83	74.53	5.46	.71	84.19	4.76	3.19	1.55	.73	5.58	22.14	77.86
610	.....do...........	10,319	10,104	515	55	9,589	9,372	5.10	2.08	18.39	73.68	5.85	.59	83.94	4.75	3.19	1.55	.60	5.97	24.99	75.01
611	.....do...........	3,637	3,652	177	....	3,385	3,411	4.97	2.07	18.88	75.13	3.92	.56	85.74	4.85	3.26	1.58	.57	4.00	4.77	95.23
612	.....do...........	3,808	3,727	185	....	3,542	3,542	4.96	2.12	19.11	74.03	4.74	.60	84.96	4.80	3.23	1.56	.61	4.84	2.74	97.26
613	.....do...........	3,862	3,792	188	....	3,604	3,469	4.96	1.80	18.01	71.96	8.23	.57	81.80	4.62	3.11	1.51	.58	8.38	3.06	96.94
614	.....do...........	3,449	3,387	168	....	3,219	3,145	4.96	1.79	18.77	72.50	6.94	.50	83.05	4.69	3.15	1.53	.51	7.07	1.82	98.18
615	.....do...........	4,479	4,398	218	....	4,180	4,136	4.96	1.80	18.17	74.36	5.67	.61	84.10	4.76	3.20	1.55	.62	5.77	3.81	96.19
616	.....do...........	4,853	4,779	236	....	4,543	4,550	4.94	1.53	18.36	75.48	4.63	.55	85.13	4.81	3.23	1.57	.56	4.70	1.89	98.11
617	.....do...........	4,433	4,351	310	....	4,041	4,170	7.12	1.85	20.31	73.89	3.95	.63	84.92	4.82	4.11	1.40	.64	4.02	1.81	98.19
618	.....do...........	3,825	3,753	268	....	3,485	3,543	7.14	1.87	18.85	73.89	5.39	.62	83.62	4.75	4.04	1.47	.63	5.47	1.32	98.68
619	.....do...........	4,556	4,469	319	....	4,150	4,271	7.14	1.92	19.77	74.07	4.24	.61	84.68	4.80	4.09	1.49	.62	4.32	1.27	98.73
627	Jamestown No. 6.	8,231	8,044	439	....	7,605	7,605	5.46	2.27	18.69	73.95	5.09	.93	84.42	4.73	3.26	1.43	.95	5.21	4.60	95.40
630	.....do...........	5,253	5,132	291	....	4,841	4,841	5.67	2.30	19.51	73.06	5.13	.74	84.56	4.72	3.28	1.43	.76	5.25	7.56	92.44
631	.....do...........	11,164	10,855	624	....	10,231	10,231	5.75	2.77	19.41	72.84	4.98	.75	84.67	4.74	3.26	1.44	.77	5.12	10.89	89.11
620	Jamestown No. 7.	5,670	5,563	269	....	5,294	5,294	4.84	1.89	18.38	75.10	4.63	.74	84.74	4.72	3.73	1.34	.75	4.72	2.12	97.88
621	.....do...........	6,300	6,134	294	....	5,840	5,840	4.79	2.64	18.44	74.33	4.59	.75	84.33	4.71	3.74	1.34	.77	4.71	1.81	98.19
623	.....do...........	7,992	7,851	464	....	7,387	7,387	5.91	1.77	18.05	74.63	5.55	.83	83.84	4.66	3.69	1.32	.84	5.65	4.51	95.49
624	.....do...........	3,815	3,750	175	....	3,575	3,575	4.67	1.70	17.82	75.90	4.58	.83	84.72	4.72	3.73	1.33	.84	4.66	....	....
625	.....do...........	5,811	5,690	335	....	5,355	5,355	5.89	2.09	15.45	76.82	5.64	1.00	83.56	4.66	3.68	1.32	1.02	5.76	1.98	98.02

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel.							Proximate analysis of fuel as fired (per cent).					Ultimate analysis of dry fuel (per cent).						Analyses of ash and refuse (per cent).	
		Total weight of fuel consumed (pounds).		Ash and refuse.		Total weight of combustible (pounds) determined from—		Ash and refuse in dry fuel (per cent).	Moisture.	Volatile.	Fixed carbon.	Ash.	Sulphur (separately determined).	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Carbon.	Earthy matter.
		As fired.	Dry.	Total (lbs.).	Clinker (per cent).	Actual weight of ash.	Analyses of ash and coal.														
1	2	32 (25)	33 (27)	34 (28)	35 (29)	36 (30)	37 (30)	38 (31)	39 (34)	40 (33)	41 (32)	42 (35)	43 (36)	44 (37)	45 (38)	46 (39)	47 (40)	48 (41)	49 (42)	50 (44)	51 (45)
626	Jamestown No. 7	7,422	7,284	392	....	6,892	6,892	5.38	1.85	16.39	76.57	5.19	1.04	83.95	4.68	3.70	1.32	1.06	5.29	1.69	98.31
639	Jamestown No. 11	6,744	6,504	339	60	6,165	6,004	5.21	3.56	15.42	75.02	6.00	.76	85.10	4.56	1.77	1.56	.79	6.22	27.63	72.37
6	Kans. No. 1	7,222	6,796	732	....	6,064	5,733	10.77	5.90	33.78	49.46	10.86	3.82	73.15	4.79	5.31	1.15	4.06	11.54	38.30	61.70
7	.....do	7,492	7,132	1,014	49	6,118	5,890	14.21	4.80	32.68	48.57	13.95	4.94	69.35	4.58	5.09	1.13	5.19	14.66	19.45	80.55
5	Kans. No. 2	5,600	5,366	627	60	4,739	....	11.70	4.18	31.23	46.68	17.91	6.27	64.57	4.41	4.82	.96	6.55	18.69	....	....
13	.....do	8,111	7,639	828	43	6,811	6,685	10.80	5.82	34.32	51.22	8.64	3.77	74.99	5.12	5.60	1.12	4.00	9.17	30.62	69.38
488	Kans. No. 2B	7,200	6,866	1,512	51	5,354	5,282	22.02	4.64	28.40	46.56	20.40	4.49	64.05	5.03	3.62	1.20	4.71	21.39	7.60	92.40
487	.....do	8,400	7,608	1,487	40	6,121	6,001	19.55	9.43	29.71	43.67	17.19	4.15	66.12	4.28	5.01	1.03	4.58	18.98	10.94	89.06
495	.....do	8,665	8,003	763	46	7,240	7,136	9.53	7.64	32.49	51.52	8.35	3.60	74.58	4.61	6.62	1.25	3.90	9.04	18.76	81.24
3	Kans. No. 3	7,700	7,544	1,045	50	6,499	6,292	13.80	2.03	33.52	50.99	13.46	5.39	70.37	4.63	4.53	1.22	5.50	13.75	20.60	79.40
4	.....do	7,101	6,941	913	60	6,028	5,764	13.15	2.25	34.30	51.05	12.40	4.80	71.83	4.72	4.62	1.23	4.91	12.69	32.51	67.49
58	Kans. No. 4	7,835	7,403	1,028	49	6,375	6,042	13.89	5.51	36.32	43.59	14.58	8.46	65.21	4.66	4.68	1.07	8.95	15.43	21.33	78.67
72	Kans. No. 5	8,651	8,278	1,009	56	7,269	6,985	12.19	4.31	32.42	51.36	11.91	4.40	71.42	4.72	5.72	1.09	4.60	12.45	26.02	73.98
311	Kans. No. 6	8,218	7,538	1,325	56	6,213	6,009	17.58	8.28	30.33	45.86	15.53	3.42	67.64	4.45	6.07	1.18	3.73	16.93	18.99	81.01
323	.....do	7,390	6,525	971	57	5,554	5,606	14.88	11.71	30.23	47.61	10.45	2.64	72.62	4.78	6.52	1.26	2.99	11.83	15.03	84.97
60	Ky. No. 1	8,355	8,114	626	52	7,488	7,396	7.72	2.89	35.61	55.59	5.91	1.19	78.54	5.17	7.12	1.85	1.23	6.09	35.80	64.20
255	Ky. No. 1C	6,102	5,842	347	55	5,495	5,415	5.94	4.26	34.48	55.70	5.56	.87	79.78	5.14	6.54	1.82	.91	5.81	25.34	74.66
263	.....do	6,086	5,815	371	49	5,444	5,271	6.38	4.45	34.51	54.72	6.32	.98	78.98	5.08	6.49	1.80	1.03	6.62	43.02	56.98
265	.....do	4,166	3,994	257	51	3,737	3,663	6.43	4.14	33.92	55.40	6.54	.98	78.82	5.07	6.47	1.80	1.02	6.82	22.69	77.31
57	Ky. No. 2	9,557	8,815	959	61	7,856	7,797	10.88	7.76	37.91	45.75	8.58	3.37	72.22	5.06	8.44	1.33	2.65	9.30	20.63	79.37
76	.....do	9,371	8,705	1,059	57	7,646	7,452	12.17	7.11	37.07	44.32	11.50	3.71	69.99	4.50	7.84	1.28	4.00	12.39	16.55	83.45
64	Ky. No. 3	9,645	8,881	916	53	7,965	7,742	10.31	7.92	37.32	44.84	9.92	3.91	70.68	4.89	7.90	1.51	4.25	10.77	19.82	80.18
62	Ky. No. 4	9,386	8,833	1,152	61	7,681	7,355	13.04	5.89	35.65	45.74	12.72	3.72	70.20	4.48	6.50	1.35	3.95	13.52	24.65	75.35
276	Ky. No. 5	8,211	7,823	271	53	7,552	7,446	3.46	4.72	34.96	56.57	3.75	.48	81.08	4.90	7.93	1.65	.50	3.94	25.96	74.04
277	.....do	6,131	5,800	342	45	5,458	5,432	5.90	5.40	34.57	56.06	3.97	.63	80.72	4.87	7.90	1.64	.67	4.20	36.65	63.35
270	Ky. No. 6	6,831	6.511	284	39	6,227	6,224	4.36	4.69	35.63	56.56	3.12	.44	81.18	5.16	8.41	1.52	.46	3.27	25.84	74.16

271	Ky. No. 6	6,780	6,440	235	30	6,205	6,156	3.65	5.01	36.23	56.09	2.67	.48	81.53	5.19	8.43	1.53	.51	2.81	43.03	56.37
278	Ky. No. 7.......	6,541	5,927	810	50	5,117	5,018	13.67	9.39	33.27	45.49	11.85	4.54	68.66	4.49	7.42	1.34	5.01	13.08	16.51	83.49
279	.....do...........	5,995	5,455	857	52	4,598	4,547	15.71	9.01	33.72	44.92	12.35	4.44	68.36	4.47	7.39	1.33	4.88	13.57	19.54	80.46
434	Ky. No. 8.......	7,698	7,255	642	29	6,613	6,510	8.85	5.76	30.36	56.21	7.67	1.28	76.87	4.72	7.65	1.26	1.36	8.14	23.96	76.04
443	.....do...........	8,400	7,935	676	30	7,259	7,072	8.52	5.53	29.68	57.05	7.74	1.10	77.01	4.73	7.65	1.26	1.16	8.19	31.55	68.45
462	Ky. No. 9B......	9,473	8,711	1,135	49	7,576	7,519	13.03	8.04	32.63	49.28	10.05	2.97	71.12	4.83	8.44	1.45	3.23	10.93	21.11	78.89
222	Md. No. 1.......	6,529	6,409	821	38	5,588	5,478	12.81	1.84	14.03	71.61	12.52	1.52	77.60	3.85	2.90	1.34	1.55	12.76	13.72	86.28
231	.....do...........	7,398	7,124	848	17	6,276	6,202	11.90	3.70	13.96	71.63	10.71	1.04	79.52	3.95	2.97	1.36	1.08	11.12	15.30	84.70
232	.....do...........	7,298	7,048	801	22	6,247	6,128	11.36	3.43	14.08	72.36	10.13	1.10	80.02	3.97	3.01	1.38	1.14	10.48	22.44	77.56
490	Md. No. 2.......	8,049	7,860	613	32	7,247	7,069	7.80	2.35	16.97	72.53	8.15	.76	82.18	4.44	2.77	1.48	.78	8.35	21.93	78.07
493	.....do...........	9,221	8,591	784	56	7,807	7,736	9.13	6.83	19.71	66.01	7.45	.86	81.52	4.33	3.44	1.79	.92	8.00	21.54	78.46
518	.....do...........	2,619	2,509	397	47	2,112	2,194	15.82	4.21	20.71	68.54	6.54	.94	83.26	4.61	2.68	1.64	.98	6.83	36.11	63.89
12	Mo. No. 1........	9,737	9,028	1,720	60	7,308	7,012	19.00	7.28	34.88	40.64	17.20	4.37	65.23	4.62	5.81	1.08	4.71	18.55	19.85	80.15
23	.....do...........	4,500	4,213	663	47	3,550	3,468	15.73	6.88	37.60	41.85	14.17	4.56	68.52	4.63	5.69	1.16	4.86	15.14	16.19	83.81
15	.....do...........	9,041	8,324	990	52	7,334	7,191	11.90	7.93	36.81	44.21	11.05	3.58	71.50	5.06	6.37	1.18	3.89	12.00	13.53	86.47
37	Mo. No. 2........	11,650	10,125	2,084	63	8,041	7,758	20.58	13.09	32.88	37.33	16.70	4.92	61.93	4.35	7.76	1.09	5.66	19.21	20.20	79.80
44	.....do...........	9,248	8,178	1,310	68	6,868	6,355	16.05	11.57	31.77	39.76	16.90	4.60	62.38	4.37	7.84	1.10	5.20	19.11	19.83	80.17
78	Mo. No. 3........	10,828	8,811	2,474	60	6,337	5,683	28.08	18.63	26.18	29.98	25.21	3.85	52.55	3.75	7.10	.88	4.73	30.99	16.08	83.92
77	.....do...........	11,044	8,749	1,047	55	7,702	7,530	11.98	20.78	31.18	39.61	8.43	2.88	70.03	5.00	9.52	1.17	3.64	10.64	27.54	72.46
70	Mo. No. 4........	9,515	8,350	556	37	7,794	7,676	6.66	12.24	40.10	42.11	5.55	4.98	76.05	5.42	5.75	.79	5.67	6.32	26.17	73.83
319	Mo. No. 5........	8,400	7,277	1,257	61	6,020	5,826	17.27	13.37	31.46	39.78	15.39	5.35	63.53	4.43	7.09	1.01	6.18	17.76	12.57	87.43
320	.....do...........	8,582	7,532	1,209	63	6,323	5,964	16.05	12.24	31.55	40.10	16.11	5.33	63.13	4.40	7.04	1.00	6.07	18.36	15.33	84.67
326	Mo. No. 6........	10,173	8,776	1,185	49	7,591	7,260	13.50	13.73	32.82	39.96	13.49	6.05	65.24	4.44	6.59	1.08	7.01	15.64	12.18	87.82
327	.....do...........	10,768	9,376	1,031	44	8,345	8,027	11.00	12.93	34.21	41.63	11.23	5.31	68.33	4.65	6.89	1.13	6.10	12.90	13.52	86.48
329	Mo. No. 7A	10,500	8,688	1,071	49	7,617	7,484	12.33	17.26	32.11	40.32	10.31	3.27	68.20	4.70	9.49	1.20	3.95	12.46	11.33	88.67
330	.....do...........	7,321	6,022	928	55	5,094	5,136	15.41	17.74	32.65	39.26	10.35	3.24	68.11	4.69	9.48	1.20	3.94	12.58	13.89	86.11
332	Mo. No. 7B......	15,400	12,665	1,295	61	11,370	10,932	10.23	17.76	32.00	39.95	10.29	3.19	67.97	4.80	9.58	1.26	3.88	12.51	11.45	88.55
486	Mo. No. 10.......	10,100	9,644	1,687	4	7,957	7,639	17.49	4.51	35.53	41.37	18.59	3.90	64.29	4.34	6.91	.91	4.08	19.47	7.59	92.41
470	Mont. No. 2......	7,700	6,985	1,207	0	5,778	5,494	17.28	9.29	31.20	42.96	16.55	.57	63.36	4.31	12.28	1.18	.63	18.24	17.89	82.11
477	Mont. No. 3.....	10,811	9,814	1,731	58	8,083	8,034	17.64	9.22	32.22	44.93	13.63	.60	65.70	4.47	13.00	1.16	.66	15.01	17.72	82.28
27	N. Mex. No. 1...	10,963	9,658	846	43	8,812	8,342	8.76	11.90	37.85	41.57	8.68	.56	70.77	4.97	12.63	1.15	.63	9.85	42.98	57.02
26	N. Mex. No. 2....	11,870	10,692	2,695	62	7,997	8,029	25.20	9.92	37.30	36.11	16.67	1.13	63.79	4.67	10.69	1.10	1.25	18.50	25.39	74.61
30	.....do...........	7,765	7,241	1,726	51	5,515	5,453	23.84	6.75	37.56	39.07	16.62	1.61	66.73	4.92	7.95	.87	1.72	17.81	28.79	71.21
396	N. Mex. No. 3A..	9,800	9,524	1,605	0	7,919	7,569	16.85	2.82	32.72	47.56	16.90	.72	68.45	4.72	7.42	1.28	.74	17.39	18.58	81.42
381	N. Mex. No. 3B..	8,742	8,479	1,273	0	7,206	6,770	15.01	3.01	32.61	47.05	17.33	.72	67.93	4.55	7.72	1.19	.74	17.87	15.26	84.74
391	.....do...........	9,902	9,657	1,474	0	8,183	7,800	15.26	2.47	32.99	47.63	16.91	.67	68.43	4.58	7.77	1.19	.69	17.34	12.43	87.57
392	.....do...........	9,796	9,329	1,098	0	8,231	7,968	11.78	4.77	33.10	49.90	12.23	.71	72.14	4.83	8.17	1.26	.75	12.85	14.81	85.19
397	N. Mex. No. 4A..	9,445	9,228	1,273	0	7,955	7,651	13.79	2.30	34.59	48.53	14.58	.60	70.54	4.89	7.48	1.56	.61	14.92	15.71	84.29
398	.....do...........	9,311	8,952	978	0	7,974	7,757	10.92	3.86	34.06	50.68	11.40	.63	73.07	5.07	7.73	1.61	.66	11.86	13.60	86.40
395	N. Mex. No. 4B..	9,025	8,721	1,112	24	7,609	7,274	12.75	3.37	34.70	48.18	13.75	.62	70.90	4.91	7.77	1.55	.64	14.23	18.49	81.51
387	N. Mex. No. 5....	8,827	8,622	1,201	0	7,421	7,071	13.93	2.32	31.80	50.23	15.65	.79	70.94	4.65	6.39	1.19	.81	16.02	14.19	85.81
33	N. Dak. No. 1...	10,680	6,852	784	17	6,068	5,389	11.44	35.84	28.13	25.40	10.63	1.68	60.39	4.05	15.57	.81	2.62	16.56	41.87	58.13
206	N. Dak. No. 3...	9,100	5,828	436	57	5,392	5,032	7.48	35.96	31.92	24.37	7.75	1.15	64.69	3.97	15.55	1.89	1.80	12.10	20.62	79.38
191	Ohio No. 1......	8,074	7,461	1,174	51	6,287	5,987	15.74	7.59	35.43	40.64	16.34	5.16	63.31	4.61	7.70	1.12	5.58	17.68	13.18	86.82
192	.....do...........	8,671	7,908	838	58	7,070	6,978	10.60	8.80	40.26	42.12	8.82	3.82	71.08	5.17	8.63	1.26	4.19	9.67	19.74	80.26
193	Ohio No. 2......	8,190	7,464	1,185	42	6,279	6,047	15.88	8.86	35.01	42.32	13.81	4.37	66.46	4.64	7.09	1.27	4.79	15.15	24.12	75.88
197	.....do...........	8,125	7,395	662	50	6,733	6,505	8.95	8.99	37.71	45.56	7.74	3.15	73.09	5.11	8.43	1.41	3.46	8.50	39.49	60.51
203	Ohio No. 3.......	9,100	8,292	784	42	7,508	7,430	9.45	8.88	34.52	48.70	7.90	1.44	73.77	4.89	9.65	1.44	1.58	8.67	18.22	81.78
188	Ohio No. 4......	8,400	8,097	877	53	7,220	7,051	10.83	3.61	37.00	49.31	10.08	3.66	73.26	4.85	6.30	1.34	3.80	10.45	22.74	77.26
201	.....do...........	7,776	7,486	806	51	6,680	6,528	10.77	3.73	36.73	49.81	9.73	2.65	74.44	4.93	6.41	1.36	2.75	10.11	24.88	75.12
202	.....do...........	7,708	7,431	738	57	6,693	6,453	9.93	3.60	35.85	50.54	10.01	3.71	73.27	4.87	6.29	1.34	3.85	10.38	27.98	72.02
219	.....do...........	7,363	7,066	620	42	6,446	6,351	8.77	4.04	38.40	50.15	7.41	3.04	76.13	5.05	6.53	1.40	3.17	7.72	27.25	72.75

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel. Total weight of fuel consumed (pounds). As fired.	Fuel. Total weight of fuel consumed (pounds). Dry.	Fuel. Ash and refuse. Total (lbs.).	Fuel. Ash and refuse. Clinker (per cent).	Fuel. Total weight of combustible (pounds) determined from— Actual weight of ash.	Fuel. Total weight of combustible (pounds) determined from— Analyses of ash and coal.	Fuel. Ash and refuse in dry fuel (per cent).	Proximate analysis of fuel as fired (per cent). Moisture.	Proximate analysis of fuel as fired (per cent). Volatile.	Proximate analysis of fuel as fired (per cent). Fixed carbon.	Proximate analysis of fuel as fired (per cent). Ash.	Proximate analysis of fuel as fired (per cent). Sulphur (separately determined).	Ultimate analysis of dry fuel (per cent). Carbon.	Ultimate analysis of dry fuel (per cent). Hydrogen.	Ultimate analysis of dry fuel (per cent). Oxygen.	Ultimate analysis of dry fuel (per cent). Nitrogen.	Ultimate analysis of dry fuel (per cent). Sulphur.	Ultimate analysis of dry fuel (per cent). Ash.	Analyses of ash and refuse (per cent). Carbon.	Analyses of ash and refuse (per cent). Earthy matter.
1	2	32 (25)	33 (27)	34 (28)	35 (29)	36 (30)	37 (30)	38 (31)	39 (34)	40 (33)	41 (32)	42 (35)	43 (36)	44 (37)	45 (38)	46 (39)	47 (40)	48 (41)	49 (42)	50 (44)	51 (45)
220	Ohio No. 4	7,881	7,542	611	34	6,931	6,859	8.10	4.30	38.86	50.15	6.69	2.97	76.80	5.10	6.61	1.40	3.10	6.99	25.60	74.40
221	.....do	4,855	4,675	885	34	4,290	....	8.24	4.30	38.86	50.15	6.69	2.97	76.80	5.10	6.61	1.40	3.10	6.99	....	....
186	Ohio No. 5	9,100	8,713	699	58	8,014	7,835	8.02	4.25	34.40	53.41	7.94	1.63	75.47	4.91	8.16	1.47	1.70	8.29	22.28	77.72
187	.....do	9,750	9,288	691	52	8,597	8,273	7.44	4.74	33.04	52.97	9.25	1.63	74.27	4.83	8.03	1.45	1.71	9.71	16.29	83.71
189	.....do	8,334	7,939	680	56	7,259	7,102	8.57	4.74	34.37	52.21	8.68	1.86	74.57	4.85	8.07	1.45	1.95	9.11	16.83	83.17
190	.....do	8,730	8,343	649	57	7,694	7,393	7.78	4.43	34.52	51.73	9.32	1.76	74.14	4.82	8.01	1.44	1.84	9.75	21.09	78.91
284	Ohio No. 6	6,718	6,469	761	52	5,708	5,520	11.76	3.71	36.58	47.64	12.07	3.77	71.82	4.84	6.26	1.13	3.91	12.54	18.07	81.93
253	.....do	5,408	5,232	346	60	4,886	4,752	6.61	3.26	38.74	51.12	6.88	3.01	76.63	5.21	6.72	1.22	3.11	7.11	31.29	68.80
268	Ohio No. 7	6,875	6,418	699	60	5,719	5,571	10.89	6.65	33.94	48.86	10.55	3.13	72.19	4.89	6.98	1.29	3.35	11.30	17.31	82.69
269	.....do	6,644	6,217	618	.63	5,599	5,412	9.94	6.42	34.20	49.14	10.24	3.30	72.34	4.90	7.00	1.29	3.53	10.94	20.16	79.84
287	Ohio No. 8	8,513	7,772	579	54	7,193	6,943	7.45	8.70	35.76	47.10	8.44	2.41	72.70	5.04	8.98	1.40	2.69	9.24	19.12	80.88
246	Ohio No. 9A	6,301	5,934	426	62	5,508	5,364	7.18	5.83	40.02	46.23	7.92	3.76	73.64	4.50	8.22	1.24	3.99	8.41	16.70	83.30
249	.....do	7,000	6,552	549	61	6,003	5,851	8.38	6.40	37.82	47.06	8.72	3.60	73.00	4.45	8.14	1.24	3.85	9.32	16.58	83.42
250	.....do	6,749	6,340	551	52	5,789	5,672	8.69	6.06	38.44	46.65	8.84	3.66	72.89	4.45	8.12	1.23	3.90	9.41	12.96	87.04
252	.... do	4,971	4,673	316	65	4,357	4,179	6.76	5.99	38.99	46.31	8.71	3.50	73.15	4.47	8.17	1.23	3.72	9.26	19.18	80.82
224	Ohio No. 9B	8,400	7,741	1,190	48	6,551	6,306	15.37	7.84	35.24	24.03	14.89	3.27	66.59	4.46	8.13	1.11	3.55	16.16	15.56	84.44
241	.....do	6,338	5,836	388	56	5,448	5,338	6.65	7.92	38.58	46.42	7.08	2.86	73.97	4.95	9.04	1.24	3.11	7.69	12.25	87.75
243	.....do	7,116	6,979	511	58	6,468	6,367	7.32	1.92	41.68	48.99	7.41	3.06	73.18	5.05	9.86	1.24	3.12	7.55	16.60	83.40
244	.....do	4,562	4,449	328	53	4,121	4,082	7.37	2.47	41.33	49.15	7.05	3.02	73.45	5.06	9.91	1.25	3.10	7.23	14.07	85.93
469	Ohio No. 10	9,711	9,313	841	47	8,472	8,322	9.03	4.10	39.55	47.54	8.81	3.60	71.28	5.30	9.15	1.32	3.76	9.19	16.02	83.98
474	Ohio No. 11	8,084	7,796	1,160	61	6,636	6,753	14.88	3.56	37.86	47.91	10.67	4.03	71.23	4.74	7.54	1.25	4.18	11.06	15.57	84.43
475	.....do	8,065	7,780	1,020	62	6,760	6,754	13.11	3.53	37.33	47.92	11.22	5.24	69.70	4.63	7.39	1.22	5.43	11.63	11.86	88.14
483	Ohio No. 12	8,750	8,439	956	55	7,483	7,417	11.33	3.55	38.35	48.37	9.73	4.00	72.82	4.91	7.29	1.24	4.15	10.09	17.92	82.08
1	Pa. No. 1	6,365	6,295	280	3	6,015	5,692	4.45	1.10	15.80	75.69	7.41	1.49	82.88	4.13	2.61	1.38	1.51	7.49	47.00	53.00
2	Pa. No. 2	6,835	6,795	223	....	6,572	6,274	3.30	.59	16.61	76.76	6.04	.91	84.45	4.25	3.04	1.28	.91	6.07	48.57	51.43
36	Pa. No. 3	8,012	7,772	1,616	44	6,156	6,036	20.79	3.00	27.62	55.00	14.38	1.13	74.09	4.42	4.44	1.08	1.16	14.81	36.12	63.88

74	Pa. No. 4	7,700	7,477	632	46	6,845	6,793	8.45	2.90	28.70	60.82	7.58	1.15	79.86	5.02	4.27	1.86	1.18	7.81	15.89	84.11
207	do	7,308	7,138	828	24	6,310	6,245	11.00	2.32	30.28	57.71	9.69	1.25	77.48	4.81	5.08	1.48	1.28	9.92	22.29	77.71
208	do	6,494	6,350	725	28	5,625	5,502	11.42	2.22	30.46	57.18	10.14	1.13	77.21	4.80	4.96	1.48	1.16	10.37	26.09	73.91
209	do	6,677	6,521	671	36	5,850	5,707	10.29	2.34	30.56	57.18	9.92	1.12	77.40	4.80	5.02	1.49	1.15	10.14	22.52	77.48
286	Pa. No. 5	7,000	6,712	494	45	6,218	6,095	7.36	4.11	32.51	55.43	7.95	1.01	78.03	4.99	6.11	1.53	1.05	8.29	12.37	87.63
194	do	7,700	7,467	399	50	7,068	7,009	5.34	3.03	35.23	56.85	4.89	.96	80.86	5.18	6.34	1.59	.99	5.04	20.50	79.50
195	do	7,512	7,289	443	40	6,846	6,787	6.08	2.97	35.11	57.19	4.73	.94	81.04	5.18	6.34	1.59	.97	4.88	32.97	67.03
217	Pa. No. 6	7,921	7,728	800	54	6,928	6,617	10.35	2.44	32.98	52.48	12.10	1.88	74.35	4.62	5.41	1.29	1.93	12.40	19.05	80.95
218	do	6,914	6,720	751	60	5,969	5,759	11.18	2.81	32.80	51.72	12.67	2.10	73.57	4.58	5.37	1.28	2.16	13.04	11.38	88.62
333	do	3,789	3,614	535	43	3,079	3,066	14.80	4.61	32.59	50.03	12.77	1.90	73.70	4.69	5.11	1.12	1.99	13.39	12.04	87.96
198	Pa. No. 7	7,175	6,927	954	51	5,973	5,862	13.77	3.45	21.79	62.20	12.56	2.63	75.36	4.42	2.93	1.55	2.73	13.01	17.24	82.76
307	do	7,088	6,677	991	0	5,686	5,563	14.84	5.80	21.79	58.78	13.63	2.22	74.41	4.37	2.86	1.53	2.36	14.47	14.93	85.07
199	do	7,159	6,815	824	33	5,991	5,914	12.09	4.80	22.64	61.62	10.94	1.62	77.64	4.56	3.00	1.60	1.70	11.50	14.31	85.69
236	Pa. No. 8	5,802	5,664	367	26	5,297	5,245	6.48	2.37	16.74	74.66	6.23	.88	84.14	4.34	2.93	1.31	.90	6.38	15.68	84.32
237	do	6,102	5,912	381	45	5,531	5,452	6.44	3.11	15.68	74.93	6.28	.89	84.03	4.35	2.91	1.31	.92	6.48	20.11	79.89
238	do	5,930	5,719	325	46	5,394	5,281	5.68	3.56	16.09	73.85	6.50	.87	83.81	4.33	2.91	1.31	.90	6.74	16.05	83.95
239	do	6,530	6,371	418	41	5,953	5,800	6.56	2.44	16.64	73.69	7.23	1.12	82.98	4.28	2.89	1.29	1.15	7.41	23.66	76.34
242	do	4,596	4,577	306	46	4,271	4,193	6.69	.42	17.51	75.20	6.87	1.01	83.35	4.15	3.27	1.32	1.01	6.90	22.21	77.79
227	Pa. No. 10	7,168	6,944	525	48	6,419	6,372	7.56	3.13	34.84	55.75	6.28	1.33	79.03	5.05	6.46	1.61	1.37	6.48	23.10	76.90
228	do	6,650	6,459	492	41	5,967	5,905	7.62	2.88	34.76	55.98	6.38	1.35	78.92	5.04	6.47	1.61	1.39	6.57	26.31	73.69
229	do	8,099	7,914	498	38	7,416	7,315	6.29	2.29	35.93	55.87	5.91	1.18	79.53	5.08	6.51	1.62	1.21	6.05	24.08	75.92
472	Pa. No. 15	6,096	5,981	892	50	5,089	5,050	14.91	1.88	17.60	69.06	11.46	5.37	75.63	4.13	1.94	1.15	5.47	11.68	26.15	73.85
473	do	7,000	6,829	933	44	5,896	5,947	13.66	2.45	17.55	70.56	9.44	3.87	78.83	4.31	2.00	1.21	3.97	9.68	23.70	76.30
467	do	6,600	6,343	735	39	5,608	5,634	11.59	3.90	23.35	64.65	8.10	3.11	78.71	4.35	4.18	1.09	3.24	8.43	23.60	76.40
468	Pa. No. 16	6,600	6,252	542	41	5,710	5,620	8.67	5.27	23.69	62.69	8.35	1.68	79.42	4.36	4.35	1.29	1.77	8.81	14.90	85.10
471	do	7,856	7,529	973	40	6,556	6,516	12.92	4.16	21.07	65.84	8.93	1.60	78.82	4.38	4.96	1.38	1.67	9.32	32.11	67.89
496	Pa. No. 17	8,400	8,110	1,087	51	7,023	6,850	13.40	3.45	28.33	55.62	12.60	1.55	74.32	4.73	4.85	1.44	1.61	13.05	18.59	81.41
506	do	7,700	7,484	880	56	6,604	6,450	11.76	2.81	27.91	57.85	11.43	1.66	75.36	4.79	4.92	1.46	1.71	11.76	17.51	82.49
499	Pa. No. 18	7,800	7,484	680	44	6,804	6,646	9.09	4.05	19.68	66.56	9.71	1.72	79.76	4.29	2.99	1.05	1.79	10.12	11.98	88.02
515	do	8,400	7,900	677	26	7,223	7,080	8.57	5.95	18.41	67.00	8.64	1.34	80.41	4.16	3.63	1.19	1.42	9.19	13.84	86.16
498	Pa. No. 19	8,125	7,865	895	46	6,970	7,012	11.38	3.20	31.65	57.32	7.83	1.51	77.11	4.86	6.94	1.44	1.56	8.09	24.25	75.75
508	do	8,400	7,970	720	34	7,250	7,156	9.03	5.12	33.00	54.36	7.52	1.05	77.93	4.76	6.86	1.41	1.11	7.93	25.32	74.68
512	Pa. No. 20	6,507	6,279	582	31	5,697	5,635	9.27	3.50	19.98	67.71	8.81	1.59	81.06	4.39	2.72	1.06	1.64	9.13	12.28	87.72
514	do	9,100	8,846	629	50	8,217	1,947	7.11	2.79	21.11	67.79	8.31	1.91	80.25	4.42	3.73	1.09	1.96	8.55	22.81	77.19
510	Pa. No. 22	7,700	7,303	827	47	6,476	6,310	11.32	5.15	29.60	55.08	10.17	1.17	75.40	4.46	6.80	1.39	1.23	10.72	25.45	74.55
401	R. I. No. 1	6,754	6,597	1,982	34	4,615	4,225	30.04	2.33	2.47	78.72	16.48	.06	79.49	.67	2.71	.18	.06	16.87	63.54	36.46
344	Tenn. No. 1	8,871	8,444	983	54	7,461	7,286	11.64	4.81	32.91	51.13	11.15	1.58	72.72	4.88	7.40	1.68	1.66	11.71	17.15	82.85
345	do	7,001	6,717	969	44	5,748	5,762	14.43	4.06	33.80	50.97	11.17	1.67	72.71	4.84	7.39	1.68	1.74	11.64	17.81	82.19
346	do	6,613	6,335	716	53	5,619	5,296	11.30	4.20	31.75	50.02	14.03	1.45	70.87	4.68	7.17	1.63	1.51	14.64	15.53	84.47
411	do	4,444	4,356	214	0	4,142	3,998	4.91	1.99	36.56	54.14	7.31	1.12	77.39	4.84	7.64	1.53	1.14	7.46	15.31	84.69
409	do	8,400	8,180	497	26	7,683	7,612	6.08	2.62	37.09	54.32	5.97	1.17	79.02	5.08	6.87	1.70	1.20	6.13	13.20	86.80
367	Tenn. No. 2	11,200	10,676	530	43	10,146	9,911	4.96	4.68	36.00	53.39	5.93	.98	78.28	5.13	7.47	1.87	1.03	6.22	19.15	80.85
368	do	8,166	7,750	612	34	7,138	7,030	7.90	5.09	35.79	52.31	6.81	.98	77.48	5.08	7.39	1.84	1.03	7.18	26.81	73.19
369	do	6,500	6,164	453	40	5,711	5,623	7.35	5.17	35.55	52.85	6.43	.95	77.84	5.10	7.42	1.86	1.00	6.78	27.25	72.75
349	Tenn. No. 3	8,342	7,893	394	47	7,499	7,190	4.99	5.38	34.54	53.03	7.05	.99	76.52	5.18	7.98	1.82	1.05	7.45	29.08	70.92
350	do	9,371	8,765	508	44	8,257	7,987	5.80	6.47	33.92	52.13	7.48	1.13	75.93	5.14	7.91	1.81	1.21	8.00	15.06	84.94
355	Tenn. No. 4	9,308	8,713	761	38	7,952	7,723	8.73	6.39	32.32	51.76	9.53	.98	74.95	5.02	7.13	1.67	1.05	10.18	13.56	86.44
356	do	10,453	9,855	837	40	9,018	8,630	8.49	5.72	31.78	51.91	10.59	.92	74.13	4.96	7.06	1.64	.98	11.23	14.06	85.94
405	do	6,600	6,410	529	25	5,881	5,836	8.25	2.88	35.78	53.84	7.50	.91	77.98	4.73	6.89	1.79	.94	7.72	14.94	85.06
352	Tenn. No. 5	8,099	7,646	734	47	6,912	6,691	9.60	5.59	33.62	51.03	9.76	3.23	74.23	4.89	5.40	1.72	3.42	10.34	22.47	77.53
357	do	9,672	9,109	768	46	8,341	8,146	8.43	5.82	33.59	51.73	8.86	2.87	75.35	4.97	5.48	1.74	3.05	9.41	13.76	86.24
358	do	9,622	8,974	732	42	8,242	7,949	8.16	6.73	32.84	51.12	9.31	2.95	74.76	4.93	5.44	1.73	3.16	9.98	17.78	82.22

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel.																		Analyses of ash and refuse (per cent).	
		Total weight of fuel consumed (pounds).		Ash and refuse.		Total weight of combustible (pounds) determined from—															
		As fired.	Dry.	Total (lbs.).	Clinker (per cent).	Actual weight of ash.	Analyses of ash and coal.													Carbon.	Earthy matter.
1	2	32 (25)	33 (27)	34 (28)	35 (29)	36 (30)	37 (30)													50 (44)	51 (45)
379	Tenn. No. 6	7,588	7,350	1,060	61	6,230	5,784	14.23	2.74	26.95	51.77	18.54	0.74	69.42	4.37	5.41	0.98	0.76	19.06	17.97	82.03
381	....do	7,700	7,457	1,174	56	6,283	5,839	15.74	3.16	28.77	52.27	17.80	.75	69.96	4.41	5.47	.98	.78	18.38	21.06	78.94
372	Tenn. No. 7A	8,736	8,476	1,094	52	7,382	7,199	12.91	2.98	34.46	49.58	12.96	3.35	71.23	4.83	5.79	1.31	3.45	12.30	13.06	86.94
373	....do	11,113	10,773	1,237	56	9,536	9,087	11.48	3.06	34.30	48.40	14.15	4.18	69.47	4.70	5.65	1.27	4.31	14.00	9.15	90.85
374	....do	7,700	7,441	969	47	6,472	6,287	13.02	3.36	33.62	49.45	13.57	3.84	70.67	4.79	5.75	1.29	3.46	14.04	11.29	88.71
406	Tenn. No. 7B	5,400	5,218	393	29	4,825	4,619	7.53	3.37	35.80	50.77	10.06	2.09	75.58	5.02	5.47	1.36	2.16	10.41	14.25	85.75
384	Tenn. Nos. 8A, 8B	6,506	6,350	987	57	5,363	5,188	15.54	2.40	32.61	50.12	14.87	5.28	69.37	4.41	4.32	1.25	5.41	15.24	19.70	80.30
385	....do	7,700	7,518	1,045	56	6,473	6,351	13.90	2.36	33.60	50.72	13.32	4.22	71.37	4.74	4.63	1.19	4.43	13.64	13.61	86.39
388	....do	8,571	8,328	813	51	7,515	7,327	9.76	2.83	34.70	52.24	10.23	2.92	75.31	5.00	4.91	1.25	3.00	10.53	15.36	84.64
363	Tenn. No. 9A	8,400	8,025	1,099	50	6,926	6,816	13.69	4.46	27.36	55.70	12.48	1.01	74.13	4.63	5.75	1.37	1.06	13.06	14.78	85.22
364	....do	9,159	8,840	1,081	55	7,759	7,586	12.23	3.48	27.86	56.34	12.32	.79	74.62	4.66	5.76	1.38	.82	12.76	11.70	88.30
365	....do	8,616	8,499	1,222	53	7,277	7,030	14.38	3.60	28.40	53.26	14.74	.78	72.43	4.52	5.61	1.34	.81	15.29	13.83	86.17
393	Tenn. No. 9B	9,270	8,877	766	40	8,111	7,877	8.63	4.24	29.80	56.10	9.86	.79	77.00	4.60	5.84	1.43	.83	10.30	11.23	88.77
407	Tenn. No. 10	3,543	3,456	517	44	2,939	2,860	14.96	2.46	30.80	51.80	14.95	1.02	71.53	4.47	6.43	1.30	1.06	15.22	15.47	84.53
408	....do	3,116	3,026	494	49	2,532	2,412	16.33	2.86	30.34	49.56	16.73	.96	69.82	4.56	6.48	.92	.99	17.23	18.91	81.09
22	Tex. No. 1	4,813	3,693	918	8	2,775	2,583	24.90	23.27	31.42	29.44	15.87	.53	62.85	3.94	10.73	1.10	.70	20.68	37.13	62.87
291	Tex. No. 4	14,941	9,522	1,151	0	8,371	8,120	12.09	36.27	30.58	25.14	8.01	.51	64.02	4.33	17.28	1.06	.80	12.57	17.78	82.22
298	....do	14,394	9,169	690	0	8,479	7,855	7.53	36.30	30.61	24.90	8.19	.50	63.83	4.32	17.15	1.06	.79	12.86	19.62	80.38
303	....do	6,560	5,368	758	28	4,610	4,314	14.12	18.17	37.80	33.43	10.60	.68	63.72	4.81	17.14	1.06	.88	12.95	47.33	52.67
402	Utah No. 2	7,000	6,193	975	0	5,218	4,957	15.74	11.53	38.91	43.83	5.73	1.36	72.15	4.70	13.86	1.27	1.54	6.48	85.61	14.39
403	....do	2,000	1,814	164	0	1,650	1,665	9.04	9.32	39.68	45.05	5.95	1.37	73.30	4.75	12.61	1.27	1.51	6.56	79.25	20.75
404	....do	7,803	7,021	981	0	6,040	5,911	13.97	10.02	39.82	43.41	6.75	1.34	71.62	4.63	13.47	1.29	1.40	7.60	59.38	40.62
281	Va. No. 1	6,825	6,510	416	49	6,094	6,045	6.39	4.62	38.85	55.92	5.61	1.06	79.12	5.08	7.56	1.28	1.13	5.88	19.66	80.34
282	....do	7,000	6,647	376	43	6,271	6,129	5.66	5.05	32.82	56.05	6.08	1.09	78.67	5.00	7.50	1.28	1.16	6.40	24.50	75.50
247	Va. No. 2	6,170	6,012	294	12	5,718	5,611	4.89	2.56	35.34	55.72	6.38	.98	79.86	5.01	7.12	1.48	1.01	5.52	23.55	76.45
261	....do	5,945	5,745	297	55	5,448	5,301	5.17	3.37	33.75	56.41	6.47	.82	79.00	4.97	7.04	1.46	.85	6.70	19.80	80.20

256	.....do........	5,843	5,596	342	47	5,254	5,120	6.11	4.22	33.48	56.11	6.19	.82	79.18	4.96	7.08	1.46	.86	6.46	33.63	66.37
260	.....do........	6,702	6,478	414	40	6,064	6,040	6.39	3.34	36.14	56.04	4.48	.85	80.74	5.05	7.21	1.49	.88	4.63	33.24	66.76
280	Va. No. 3........	6,000	5,896	481	46	5,415	5,482	8.16	1.73	33.25	60.35	4.67	.64	82.80	4.98	5.18	1.64	.65	4.75	27.88	72.12
283	.....do........	6,200	5,996	339	36	5,657	5,599	5.65	3.29	32.00	60.20	4.51	.56	82.95	4.98	5.19	1.64	.58	4.66	34.47	65.53
240	Va. No. 4........	6,411	6,193	285	51	5,908	5,758	4.60	3.40	36.01	55.87	4.72	.49	80.44	4.99	7.79	1.38	.51	4.89	46.33	53.67
248	.....do........	5,781	5,572	335	....	....	5,220	....	3.62	35.84	56.58	3.96	.44	81.15	5.03	7.86	1.39	.46	4.11	36.86	63.14
254	.....do........	7,611	7,297	496	....	....	6,884	....	4.18	36.18	56.09	3.60	.44	81.44	5.05	7.89	1.40	.46	3.76	28.00	72.00
476	Va. No. 5A.......	9,100	8,670	2,251	51	6,419	6,304	25.96	4.73	11.64	65.05	18.58	.67	72.22	3.53	3.36	.69	.70	19.50	29.97	70.03
482	.....do........	9,800	9,349	1,813	62	7,536	7,222	19.39	4.60	11.51	66.51	17.38	.60	73.45	3.58	3.42	.70	.63	18.22	23.39	76.61
494	Va. No. 5B.......	6,000	5,699	1,033	46	4,666	4,605	18.13	5.02	15.52	64.51	14.95	.84	75.82	3.66	3.02	.88	.88	15.74	19.10	80.90
507	Va. No. 6........	7,700	7,409	941	51	6,468	6,347	12.70	3.78	23.08	63.85	9.29	1.16	78.41	4.45	4.93	1.35	1.21	9.65	36.87	63.13
290	Wash. No. 1B...	9,473	7,961	1,395	0	6,566	6,399	17.52	15.96	34.53	37.43	12.08	.58	66.09	4.77	12.74	1.34	.69	14.37	29.93	70.07
359	Wash. No. 2.....	8,299	8,037	1,052	61	6,985	6,874	13.09	3.16	36.49	48.09	12.26	.38	71.62	4.96	9.09	1.28	.39	12.66	13.75	86.25
360	.....do........	9,594	9,248	1,120	55	8,128	8,008	12.11	3.61	35.63	48.95	11.81	.39	71.95	4.98	9.12	1.29	.41	12.25	9.56	90.44
361	.....do........	9,223	8,892	1,124	48	7,768	7,710	12.64	3.59	35.97	48.85	11.59	.37	72.16	4.99	9.15	1.29	.38	12.08	10.09	89.91
412	.....do........	7,800	7,593	843	26	6,750	6,670	11.10	2.66	37.39	48.89	11.06	.39	73.02	4.86	8.88	1.48	.40	11.36	7.10	92.90
24	W. Va. No. 1.....	7,818	7,669	596	54	7,073	6,938	7.77	1.90	34.64	56.25	7.21	.98	78.53	5.13	6.43	1.56	1.00	7.35	28.99	71.01
25	W. Va. No. 2.....	8,354	8,186	808	56	7,378	7,104	9.89	2.01	39.23	48.80	9.96	2.71	74.36	4.93	6.40	1.37	2.77	10.17	30.94	69.06
28	W. Va. No. 3.....	8,225	8,016	977	51	7,039	6,875	12.19	2.54	30.31	66.11	11.04	1.38	75.86	4.78	5.17	1.44	1.42	11.38	23.83	76.17
31	W. Va. No. 4....	7,895	7,695	819	50	6,876	6,675	10.64	2.53	27.64	59.84	9.99	.96	77.42	4.69	5.18	1.48	.98	10.25	28.24	71.76
34	W. Va. No. 5.....	7,700	7,538	808	37	6,730	6,544	10.72	2.11	28.95	58.66	10.28	1.01	76.49	4.74	5.76	1.48	1.08	10.50	25.01	74.99
39	W. Va. No. 6....	7,406	7,248	504	45	6,740	6,639	7.01	2.14	22.38	70.03	5.45	.70	83.71	4.64	3.67	1.70	.71	5.57	40.32	59.68
43	.....do........	7,264	7,111	498	49	6,613	6,582	7.00	2.11	21.44	71.42	5.03	.64	84.16	4.66	3.68	1.71	.65	5.14	43.02	56.98
51	W. Va. No. 7....	7,700	7,494	623	62	6,871	6,599	8.81	2.68	20.23	68.27	8.82	1.52	79.27	4.13	4.97	1.01	1.56	9.06	34.60	65.40
53	W. Va. No. 8.....	7,997	7,576	754	44	6,822	6,840	9.95	5.26	31.19	56.68	6.87	.74	80.37	5.08	5.12	1.40	.78	7.25	23.64	76.36
69	W. Va. No. 9....	7,464	7,209	573	43	6,636	6,625	7.95	3.42	31.11	59.47	6.00	.82	80.70	5.01	5.57	1.66	.85	6.21	23.68	76.32
54	W. Va. No. 10....	7,441	7,312	643	41	6,669	6,582	8.79	1.74	18.23	73.84	6.19	.59	84.92	4.46	2.66	1.06	.60	6.30	41.90	58.10
56	W. Va. No. 11....	7,700	7,327	1,021	49	6,306	6,253	13.93	4.85	16.81	68.86	10.48	.47	80.34	4.00	3.11	1.05	.49	11.01	26.13	73.87
46	W. Va. No. 12....	7,399	7,282	584	52	6,698	6,660	8.02	1.58	18.26	75.33	4.83	.59	86.14	4.41	2.56	1.88	.60	4.91	45.43	54.57
59	.....do........	7,515	7,341	760	60	6,581	6,626	10.35	2.32	24.02	67.46	6.20	.84	84.82	4.95	1.67	1.35	.87	6.34	32.77	67.23
179	W. Va. No. 13....	6,925	6,676	262	40	6,414	6,308	3.92	3.59	30.88	61.69	3.84	.94	83.64	5.09	4.93	1.38	.98	3.98	39.01	60.99
180	.....do........	6,425	6,134	263	41	5,871	5,755	4.29	4.53	29.82	61.38	4.27	.85	83.30	5.07	4.90	1.37	.89	4.47	39.92	60.08
178	W. Va. No. 14....	6,001	5,830	102	46	5,728	5,636	1.75	2.85	30.13	64.78	2.24	1.06	83.41	5.07	6.51	1.63	1.09	2.31	58.09	41.91
181	.....do........	6,274	5,951	....	....	....	5,634	....	5.15	28.38	64.09	2.38	1.11	83.16	5.06	6.50	1.60	1.17	2.51	45.70	54.30
214	W. Va. No. 15....	5,317	5,216	846	46	4,370	4,383	16.22	1.90	38.18	51.90	8.02	3.01	77.45	4.97	4.87	1.46	3.07	8.18	48.07	51.93
215	.....do........	6,796	6,628	567	46	6,061	5,938	8.55	2.47	38.38	51.48	7.67	2.77	77.93	5.00	4.90	1.47	2.84	7.86	29.72	70.28
216	.....do........	2,143	5,003	369	49	4,634	4,495	7.38	2.73	38.43	51.11	7.73	2.71	77.90	5.00	4.89	1.47	2.79	7.95	29.83	70.17
304	W. Va. No. 16A..	4,200	4,027	355	51	3,672	3,588	8.82	4.12	33.83	54.05	8.00	1.17	77.43	4.99	6.44	1.58	1.22	8.34	29.12	70.88
305	.....do........	3,796	3,538	264	61	3,274	3,195	7.46	6.79	31.71	53.61	7.89	1.09	77.38	4.98	6.44	1.57	1.17	8.46	16.48	83.52
225	W. Va. No. 17....	6,170	5,915	580	43	5,335	5,336	9.81	4.14	27.89	60.87	7.10	1.28	80.79	4.51	4.51	1.44	1.34	7.41	24.21	75.79
226	.....do........	6,639	6,367	630	34	5,737	5,732	9.89	4.10	27.92	60.58	7.40	1.21	80.59	4.49	4.50	1.44	1.26	7.72	22.82	77.18
230	.....do........	6,756	6,462	550	48	5,912	5,894	8.51	4.35	28.35	61.13	6.17	1.36	81.56	4.55	4.57	1.45	1.42	6.45	27.52	72.48
261	W. Va. No. 18....	6,679	6,477	464	32	6,013	5,956	7.16	3.02	32.79	57.66	6.53	.66	80.08	4.79	6.26	1.46	.68	6.78	18.39	81.61
262	.....do........	7,700	7,489	467	34	7,022	6,883	6.24	2.74	32.52	58.02	6.72	.69	79.91	4.78	6.24	1.45	.71	6.91	19.09	80.91
285	W. Va. No. 19....	5,789	5,648	320	56	5,328	5,141	5.67	2.44	20.59	70.43	6.54	.92	82.72	4.54	3.51	1.59	.94	6.70	39.86	60.14
289	.....do........	4,640	4,498	444	48	4,054	4,030	9.87	3.07	20.58	69.66	6.69	1.04	82.43	4.52	3.49	1.59	1.07	6.90	35.42	64.58
331	.....do........	3,500	3,345	302	50	3,043	3,075	9.03	4.43	22.87	66.71	5.99	1.03	82.15	4.84	4.10	1.56	1.08	6.27	19.86	80.14
272	W. Va. No. 20....	5,704	5,578	535	48	5,043	5,031	9.59	2.21	32.55	57.31	7.93	1.28	79.20	5.00	5.00	1.38	1.31	8.11	17.83	82.17
273	.....do........	6,129	5,952	477	34	5,475	5,343	8.01	2.89	31.75	56.93	8.43	1.50	78.49	4.95	4.97	1.37	1.54	8.68	19.25	80.75
264	.....do........	6,479	6,253	422	33	5,831	5,833	6.75	3.49	32.94	58.37	5.20	1.06	81.75	5.17	5.16	1.43	1.10	5.39	19.74	80.26
266	.....do........	6,584	6,377	369	45	6,008	5,948	5.79	3.14	33.40	57.93	5.53	1.10	81.45	5.15	5.13	1.42	1.14	5.71	17.70	82.30
274	W. Va. No. 21...	5,950	5,736	307	60	5,429	5,440	5.35	3.60	36.30	55.44	4.66	1.03	80.77	5.15	6.62	1.56	1.07	4.83	6.04	93.96

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel.							Proximate analysis of fuel as fired (per cent).					Ultimate analysis of dry fuel (per cent).						Analyses of ash and refuse (per cent).	
		Total weight of fuel consumed (pounds).		Ash and refuse.		Total weight of combustible (pounds) determined from—		Ash and refuse in dry fuel (per cent).	Moisture.	Volatile.	Fixed carbon.	Ash.	Sulphur (separately determined).	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Carbon.	Earthy matter.
		As fired.	Dry.	Total (lbs.).	Clinker (per cent).	Actual weight of ash.	Analyses of ash and coal.														
1	2	32 (25)	33 (27)	34 (28)	35 (29)	36 (30)	37 (30)	38 (31)	39 (34)	40 (33)	41 (32)	42 (35)	43 (36)	44 (37)	45 (38)	46 (39)	47 (40)	48 (41)	49 (42)	50 (44)	51 (45)
275	W. Va. No. 21	6,300	6,054	432	54	5,622	5,586	7.14	3.90	34.31	55.75	6.04	1.13	79.43	5.06	6.52	1.53	1.18	6.28	20.38	79.62
296	.....do	5,444	5,258	378	47	4,880	4,812	7.19	3.42	34.26	56.20	6.12	1.22	79.33	5.04	6.51	1.52	1.26	6.34	29.88	70.12
267	.....do	7,162	6,858	338	52	6,520	6,511	4.93	4.24	36.46	55.63	3.67	1.07	81.58	5.19	6.72	1.56	1.12	3.83	24.85	75.15
446	W. Va. No. 22A	8,299	7,848	1,281	33	6,567	6,398	16.32	5.44	29.31	51.64	13.61	.95	72.02	4.72	6.72	1.15	1.00	14.39	25.01	74.99
447	.....do	8,400	7,934	1,006	33	6,928	6,554	12.68	5.55	29.65	51.33	13.47	1.04	72.03	4.72	6.74	1.15	1.10	14.26	24.63	75.37
454	.....do	8,982	8,511	712	25	7,799	7,738	8.36	5.24	33.67	54.99	6.10	.90	78.82	5.17	7.36	1.26	.95	6.44	31.63	68.37
438	W. Va. No. 22B	8,806	8,505	688	20	7,817	7,676	8.09	3.42	33.49	55.27	7.82	.83	77.13	4.96	7.71	1.24	.86	8.10	20.38	79.62
439	W. Va. No. 23A	8,233	8,064	932	40	7,132	7,048	11.56	2.05	34.71	55.14	8.10	1.35	77.14	4.95	7.05	1.21	1.38	8.27	37.46	62.54
440	.....do	7,700	7,499	905	38	6,594	6,490	12.07	2.61	34.15	53.96	9.28	1.52	75.91	4.88	6.94	1.18	1.56	9.53	32.46	67.54
444	W. Va. No. 23B	7,440	7,138	739	30	6,399	6,462	10.35	4.06	35.70	55.44	4.80	.95	80.44	5.20	6.84	1.53	.99	5.00	43.11	56.89
445	.....do	7,940	7,746	1,040	41	6,706	6,524	13.43	2.44	33.30	53.67	10.59	1.40	75.06	4.86	6.38	1.42	1.43	10.85	36.67	63.33
63	Wyo. No. 1	11,946	9,341	810	25	8,531	8,138	8.67	21.81	40.56	31.61	6.02	.63	69.46	4.90	15.83	1.30	.81	7.70	59.81	40.19
61	Wyo. No. 2	12,028	10,693	3,037	....	7,656	8,014	28.40	11.10	35.55	34.58	18.77	3.87	58.16	4.47	11.07	.84	4.35	21.11	13.86	86.14
196	Wyo. No. 2B	10,024	9,058	2,373	0	6,685	6,651	26.20	9.64	34.75	34.68	20.93	4.32	58.01	4.23	8.93	.89	4.78	23.16	13.02	86.98
210	.....do	10,414	9,419	2,457	0	6,962	7,154	26.09	9.55	35.75	35.73	18.97	3.95	60.09	4.39	9.25	.92	4.37	20.98	11.82	88.18
213	.....do	13,060	11,892	2,813	0	9,079	8,742	23.65	8.94	35.90	33.70	21.46	5.03	57.08	4.16	8.80	.87	5.52	23.57	12.37	87.63
211	Wyo. No. 3	8,166	6,931	1,159	60	5,772	5,325	16.72	15.12	34.36	33.82	16.70	6.66	56.73	4.15	10.77	.83	7.85	19.67	20.99	79.01
212	.....do	10,770	9,305	1,493	58	7,812	7,285	16.05	13.60	36.12	34.07	16.21	7.90	56.44	4.12	10.72	.82	9.14	18.76	18.36	81.64
223	.....do	8,048	6,512	685	53	5,827	5,804	10.52	19.08	36.58	37.56	6.78	4.26	67.60	4.94	12.83	.99	5.26	8.38	23.82	76.18
399	Wyo. No. 4	11,116	9,738	1,159	64	8,579	8,450	11.90	12.40	39.75	41.08	6.77	.26	70.30	5.70	15.60	.97	.30	7.73	46.20	53.80
400	Wyo. No. 6	12,161	9,919	1,096	14	8,823	8,539	11.05	18.44	36.35	40.68	4.53	.57	71.98	5.21	15.42	1.19	.70	5.55	75.60	24.40
419	.....do	6,383	5,389	798	0	4,596	4,516	14.72	15.57	38.74	42.87	2.82	.59	74.59	4.99	15.35	1.08	.70	3.34	87.37	12.63

	MISCELLANEOUS.																				
451	Argentine Republic No. 1...	8,638	8,039	3,904	60	4,135	2,971	48.56	6.94	16.87	26.08	50.16	.60	34.42	2.40	7.74	.89	.64	53.91	18.82	81.18
458	.....do...........	9,300	7,767	2,889	48	4,878	4,280	37.20	16.48	17.96	34.23	31.33	.65	46.73	3.26	10.51	1.21	.78	37.51	19.87	80.13
485	.....do...........	3,900	3,559	1,471	60	2,088	1,771	41.33	8.75	21.45	33.75	36.05	.80	47.51	3.41	7.77	.92	.88	39.51	25.95	74.05
172	Brazil No. 1.....	5,507	4,906	1,140	0	3,706	3,372	23.24	10.92	27.06	37.49	24.53	2.69	56.70	3.71	8.08	.95	8.02	37.54	16.06	83.94
173	.....do...........	6,350	5,660	1,407	0	4,253	3,856	24.86	10.87	26.00	38.32	24.81	4.04	55.23	3.61	7.86	.98	4.53	27.84	16.23	83.77
	Mixed coals (accurately sized):																				
348	1½ to 3 inches..	11,200	9,374	1,355	71	8,019	8,071	14.45	16.30	30.43	43.38	9.89	1.91	69.53	4.82	10.15	1.40	2.28	11.82	14.44	85.56
347	1 to 1½ inches..	6,441	5,389	812	63	4,577	4,522	15.07	16.34	29.76	42.08	11.82	2.36	67.89	4.39	9.56	1.21	2.82	14.13	12.93	87.07
351	¾ to 1 inch.....	6,689	5,543	812	60	4,731	4,651	14.65	17.13	29.08	41.86	11.93	2.06	68.02	4.56	9.19	1.35	2.49	14.39	11.52	88.48
362	½ to ¾ inch.....	5,232	4,362	478	62	3,884	3,630	10.96	16.62	27.74	42.83	12.81	2.36	66.72	4.17	9.88	1.04	2.83	15.36	12.95	87.05
366	⅜ to ½ inch.....	5,080	4,122	557	67	3,565	3,419	13.51	18.86	29.34	39.42	12.38	2.10	67.61	4.29	9.16	1.09	2.59	15.26	13.28	86.72
370	¼ to ⅜ inch.....	3,790	3,173	557	59	2,616	2,563	17.55	16.28	28.14	41.15	14.43	2.30	65.87	4.16	8.77	1.21	2.75	17.24	11.31	88.69
371	Under ¼ inch..	4,623	3,819	780	45	3,039	2,820	20.42	17.39	25.33	39.88	17.40	1.92	62.41	3.68	9.43	1.10	2.32	21.06	24.98	75.02
	Mixed coals:																				
245	Pa. No. 8 dried and Va. No. 4	5,600	5,433	356	42	5,077	4,944	6.55	2.99	28.16	63.30	5.55	.70	81.24	4.46	6.45	1.41	.72	5.72	50.10	49.90
414	Utah No. 1 and R. I. No. 1...	3,827	3,733	458	46	3,275	3,217	12.27	2.45	24.21	62.60	10.74	.41	78.63	2.95	6.25	.74	.42	11.01	22.92	77.08
415	.......do.	3,946	3,856	474	44	3,382	3,334	12.29	2.27	22.20	65.29	10.24	.41	77.64	3.13	7.59	.74	.42	10.48	24.98	75.02
416	Utah No. 2 and R. I. No. 1...	11,438	10,769	2,900	0	7,869	7,353	26.98	5.85	25.20	59.56	9.39	.85	76.42	2.94	9.04	.73	.90	9.97	80.75	19.25
	Special tests:																				
500	Illinois.........	10,500	9,178	1,086	55	8,092	8,053	11.83	12.59	35.94	42.34	9.13	3.24	70.33	4.95	9.46	1.11	3.71	10.44	15.34	84.66
501	.......do.........	6,643	5,774	704	59	5,070	5,062	12.19	13.08	35.34	42.62	8.94	3.16	70.51	4.97	9.47	1.12	3.64	10.29	16.55	83.45
502	.......do.........	9,100	7,826	983	65	6,843	6,798	12.56	14.00	33.85	42.45	9.70	3.36	69.48	4.90	9.34	1.09	3.91	11.28	14.77	85.23
503	.......do.........	8,400	7,220	1,004	56	6,216	6,123	13.91	14.05	33.64	41.37	10.94	3.35	68.30	4.81	9.18	1.08	3.90	12.73	17.70	82.30
504	.......do.........	7,000	6,244	737	62	5,507	5,496	11.80	10.80	36.76	42.81	9.63	3.31	70.03	4.93	9.42	1.11	3.71	10.80	9.98	90.02
505	.......do.........	10,500	9,072	1,150	57	7,922	7,894	12.68	13.60	35.17	41.51	9.72	3.22	69.65	4.91	9.36	1.10	3.73	11.25	13.71	86.29
517	.......do.........	4,200	3,697	754	66	2,943	3,150	20.39	11.98	35.11	43.83	9.08	2.85	70.81	4.99	9.53	1.11	3.24	10.32	21.84	78.16
479	Washery refuse..	11,900	10,611	5,528	69	5,083	4,688	52.10	10.83	17.21	30.14	41.82	2.40	39.81	2.83	7.09	.68	2.69	46.90	17.14	82.86
519	Mixed coke......	10,800	10,093	1,274	59	8,819	8,424	12.62	6.55	.81	79.78	12.86	.97	81.34	.57	2.40	.89	1.04	13.76	21.98	78.02

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds).						Calorific value of fuel per pound (B. t. u.).				Quality of steam (per cent).		Water evaporation.							
			Combustible determined from—			Combustible per sq. ft. of water-heating surface determined from—		By oxygen calorimeter.		By analysis.				Water fed to boiler (pounds).					Per hour (pounds).		
		Dry.	Actual w'ght of ash.	Analyses of ash and coal.	Dry per sq. ft. of grate area.	Actual weight of ash.	Analysis of ash.	Dry fuel.	Combustible.	Dry fuel.	Combustible.	Moisture.	Factor of correction (dry steam-unity.)	Total weight.	Equivalent from and at 212° F.	Actually corrected for quality of steam (lbs.).	Factor.	Equivalent converted into dry steam from and at 212° F. (lbs.).	Corrected for quality of steam.	Equivalent from and at 212° F. Total.	Equivalent from and at 212° F. Per sq. ft. of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
17	Ala. No. 1.....	841	704	685	20.72	0.346	0.337	12,937	15,094	12,967	15,129	0.62	0.9952	60,769	71,513	60,477	1.1768	71,169	6,030	7,096	3.49
21	.....do.........	770	667	644	18.97	.328	.317	13,102	15,194	13,025	15,105	.88	.9932	47,578	56,332	47,254	1.1840	55,949	5,728	6,782	3.34
16	Ala. No. 2.....	874	754	731	21.54	.371	.360	12,555	14,638	12,353	14,402	.43	.9966	63,697	75,060	63,482	1.1784	74,807	6,336	7,465	3.67
382	Ala. No. 2B...	954	823	803	23.53	.405	.395	12,411	14,462	12,193	14,208	.25	.9981	66,285	78,800	66,159	1.1888	78,650	6,616	7,865	3.87
383	.....do.........	700	591	579	17.26	.291	.285	12,269	14,466	12,055	14,214	.26	.9980	48,527	57,679	48,430	1.1886	57,564	4,829	5,739	2.83
410	.....do.........	735	646	623	18.13	.318	.307	12,856	14,765	12,942	14,864	1.69	.9870	57,024	66,929	56,283	1.1737	66,059	5,640	6,619	3.26
390	Ala. No. 3.....	839	693	641	20.69	.341	.316	11,806	15,024	11,648	14,823	1.78	.9863	57,830	68,112	57,038	1.1778	67,179	5,704	6,718	3.31
294	.....do.........	853	720	673	21.04	.355	.331	12,175	15,025	12,011	14,823	1.33	.9898	58,819	69,377	58,219	1.1795	68,669	5,822	6,867	3.38
375	Ala. No. 4.....	849	758	734	20.94	.373	.361	13,671	15,347	13,811	15,504	.49	.9962	66,277	79,022	66,025	1.1923	78,722	6,492	7,741	3.81
376	.....do.........	705	606	576	17.39	.298	.284	13,041	15,346	13,176	15,505	.75	.9942	49,809	59,243	49,520	1.1894	58,899	5,069	6,029	2.97
377	.....do.........	748	637	583	18.45	.314	.287	12,447	15,361	12,577	15,521	.75	.9943	53,328	63,402	53,024	1.1889	63,041	5,302	6,304	3.10
378	.....do.........	645	556	536	15.91	.274	.264	13,244	15,395	13,383	15,556	1.93	.9851	38,507	45,704	37,933	1.1869	45,023	4,723	5,607	2.76
413	.....do.........	856	781	769	21.11	.385	.379	13,932	15,300	13,637	14,976	.75	.9943	67,116	78,593	66,733	1.1710	78,144	6,761	7,917	3.90
478	Ala. No. 5.....	771	604	578	19.01	.297	.285	11,932	15,115	11,918	15,098	.32	.9976	49,239	59,530	49,121	1.2090	59,387	4,947	5,981	2.94
480	.....do.........	927	753	711	22.86	.371	.350	12,335	15,187	12,305	15,150	.43	.9967	60,174	72,732	59,975	1.2087	72,492	6,267	7,575	3.73
484	Ala. No. 6.....	820	745	739	20.22	.367	.364	24,449	15,634	14,270	15,440	.29	.9978	64,303	78,057	64,162	1.2014	77,886	6,697	8,130	4.00
9	Ark. No. 1.....	688	601	581	16.90	.296	.286	13,572	15,654	13,297	15,337	1.72	.9868	53,726	63,531	53,017	1.1825	62,693	5,265	6,226	3.06
14	.....do.........	760	674	662	18.74	.332	.326	13,837	15,426	13,885	15,479	.73	.9944	60,804	71,840	60,464	1.1815	71,438	6,026	7,120	3.51
8	Ark. No. 2.....	640	585	568	15.70	.288	.280	14,245	15,570	14,269	15,596	2.45	.9811	54,065	63,953	53,044	1.1829	62,745	5,268	6,231	3.06
11	.....do.........	702	608	601	17.31	.299	.296	13,554	15,572	13,465	15,470	.49	.9963	55,341	65,529	55,136	1.1841	65,286	5,523	6,540	3.22

39	Ark. No. 3.....	798	697	680	19.68	.343	.335	14,151	15,626	13,788	15,226	.43	.9967	64,237	76,242	63,992	1.1875	75,991	6,388	7,586	3.74
35	.....do.........	831	683	656	20.49	.336	.323	12,088	15,566	12,533	15,376	.60	.9954	58,830	70,170	58,559	1.1928	69,847	5,808	6,927	3.41
40	Ark. No. 4.....	787	669	650	19.41	.329	.320	13,954	15,595	13,853	15,482	.56	.9958	61,759	73,937	61,500	1.1972	73,628	6,181	7,400	3.64
42	.....do.........	721	542	524	17.78	.265	.258	13,905	15,908	13,738	15,717	.93	.9929	34,034	40,763	33,791	1.1977	40,471	4,805	5,754	2.83
41	Ark. No. 5.....	868	675	685	21.42	.333	.337	13,617	15,434	13,602	15,417	.51	.9961	59,367	71,050	59,135	1.1968	70,773	5,836	6,984	3.44
293	Ark. No. 7A...	556	473	479	13.71	.233	.266	13,705	15,352	13,720	15,369	2.32	.9823	43,541	52,619	42,770	1.2085	51,688	4,364	5,274	2.60
294	.....do.........	703	621	600	17.34	.306	.295	13,531	15,346	13,543	15,360	1.87	.9856	52,136	63,006	51,385	1.2085	62,099	5,139	6,210	3.06
297	Ark. No. 8.....	752	604	587	18.55	.297	.289	13,000	15,372	12,938	15,299	2.75	.9790	50,505	61,131	49,444	1.2104	59,847	5,087	6,157	3.03
308	.....do.........	654	533	542	16.13	.263	.267	14,125	15,449	14,047	15,364	1.07	.9918	24,525	29,727	24,324	1.2121	29,483	4,836	5,861	2.89
309	.....do.........	897	801	766	22.12	.394	.377	14,153	15,441	14,085	15,367	.67	.9949	32,084	38,934	31,920	1.2135	38,735	6,346	7,701	3.79
340	Ark. No. 10....	1,286	1,111	992	35.33	.547	.488	9,549	12,180	9,362	11,941	1.22	.9906	56,499	68,465	55,968	1.2118	67,822	6,219	7,536	3.71
75	Colo. No. 1....	722	619	609	17.80	.304	.300	12,577	13,478	12,296	13,178	.53	.9960	43,141	52,123	42,968	1.2082	51,914	4,311	5,209	2.56
386	Fla. No. 1.....	1,358	1,287	1,238	33.49	.634	.610	10,082	11,003	9,686	10,571	.75	.9943	28,482	33,575	28,320	1.1788	33,384	6,958	8,202	4.04
481	Ga. No. 1......	905	728	711	22.32	.358	.350	12,865	15,647	12,433	15,120	.74	.9943	63,679	77,166	63,316	1.2118	76,726	6,686	8,102	3.99
18	Ill. No. 1......	1,012	832	809	24.90	.410	.398	11,855	14,252	11,673	14,033	.45	.9965	61,615	72,661	61,398	1.1794	72,413	6,183	7,292	3.59
19	Ill. No. 2......	907	814	787	22.36	.401	.388	12,569	14,159	12,683	14,287	.42	.9968	61,468	72,551	61,269	1.1803	72,315	6,145	7,253	3.57
38	Ill. No. 3......	861	726	707	21.23	.357	.348	12,857	14,712	12,645	14,470	.80	.9939	58,988	70,544	58,628	1.1959	70,113	5,786	6,919	3.41
48	Ill. No. 4......	805	689	679	19.84	.339	.334	12,427	14,323	12,339	14,222	......	.9900	50,487	60,342	49,982	1.1952	59,738	4,963	5,932	2.92
50	.....do.........	938	809	791	23.13	.398	.389	12,459	14,319	12,362	14,207	.70	.9947	57,403	68,729	57,099	1.1973	68,365	5,700	6,825	3.36
73	Ill. No. 6......	906	764	728	22.34	.376	.358	11,594	13,992	11,336	13,681	.58	.9957	54,989	66,746	54,750	1.2138	66,456	5,521	6,702	3.30
106	Ill. No. 6B....	1,052	938	926	25.94	.462	.456	12,762	14,229	12,515	13,954	.72	.9945	58,330	69,424	58,009	1.1902	69,042	5,801	6,904	3.39
313	.....do.........	699	607	588	17.24	.299	.290	12,028	13,936	11,767	13,633	1.08	.9917	26,181	31,734	25,964	1.2121	31,471	4,704	5,701	2.81
314	.....do.........	1,006	876	846	24.81	.431	.417	12,101	14,175	11,905	13,945	.99	.9924	23,824	28,903	23,643	1.2132	28,684	5,725	6,945	3.42
122	Ill. No. 7C....	731	526	496	20.08	.259	.244	9,999	13,944	10,021	13,974	2.52	.9805	38,792	45,697	38,035	1.1780	44,805	4,777	4,449	2.19
129	.....do.........	808	714	708	19.92	.351	.348	12,730	14,255	12,685	14,205	1.56	.9880	46,478	54,858	45,920	1.1803	54,199	5,499	6,490	3.19
142	Ill. No. 7D....	814	682	653	20.07	.336	.321	11,673	14,251	11,531	14,078	2.03	.9843	52,155	61,444	51,336	1.1781	60,479	5,123	6,036	2.97
143	.....do.........	760	634	590	18.74	.312	.291	11,212	14,108	11,120	13,993	2.46	.9808	47,373	55,791	46,463	1.1777	54,719	4,646	5,472	2.69
146	.....do.........	736	597	556	20.21	.294	.274	11,088	14,107	10,948	13,929	.66	.9949	46,917	55,156	46,678	1.1756	54,875	4,635	5,449	2.68
516	Ill. No. 7E....	1,297	945	915	31.99	.465	.451	10,283	13,894	10,033	13,556	.23	.9983	48,638	59,047	48,555	1.2140	58,946	6,185	7,509	3.70
101	Ill. No. 8......	1,049	880	842	28.82	.433	.415	12,047	14,113	11,900	13,941	1.21	.9907	55,394	66,074	54,879	1.1928	65,460	5,470	6,526	3.21
102	.....do.........	1,150	993	955	28.36	.489	.470	12,002	14,120	11,912	14,014	.78	.9940	62,010	73,978	61,638	1.1930	73,534	6,164	7,353	3.62
103	Ill. No. 9A....	1,076	947	931	26.53	.466	.458	12,506	14,187	12,479	14,157	1.85	.9857	62,421	74,450	61,528	1.1927	73,384	6,141	7,324	3.61
104	.....do.........	942	822	802	23.22	.405	.395	12,483	14,297	12,368	14,166	1.56	.9880	51,506	61,308	50,888	1.1903	60,572	5,140	6,118	3.01
105	.....do.........	1,227	1,101	1,062	30.26	.542	.523	12,555	14,278	12,429	14,135	.49	.9963	69,910	83,361	69,651	1.1924	83,052	6,944	8,280	4.08
113	.....do.........	931	838	827	25.60	.413	.407	12,947	14,184	13,007	14,250	1.56	.9880	52,780	62,655	52,147	1.1871	61,904	5,225	6,203	3.05
121	Ill. No. 9B....	968	843	821	26.60	.415	.404	12,438	14,303	12,292	14,135	1.16	.9911	61,582	72,593	61,034	1.1788	71,947	6,146	7,245	3.57
492	Ill. No. 9C....	913	776	760	22.52	.382	.374	12,037	14,371	11,722	13,995	.30	.9977	58,924	71,310	58,788	1.2102	71,145	5,879	7,115	3.50
107	Ill. No. 10.....	851	731	711	21.00	.360	.350	12,429	14,545	12,251	14,337	1.09	.9916	56,168	66,806	55,696	1.1894	66,245	5,477	6,514	3.20
108	.....do.........	902	784	767	22.24	.386	.378	12,685	14,550	12,508	14,347	1.04	.9920	53,776	64,015	53,346	1.1904	63,503	5,335	6,350	3.13
109	.....do.........	781	656	632	21.46	.323	.311	12,373	14,546	12,197	14,339	.67	.9949	50,700	60,338	50,441	1.1901	60,030	5,054	6,015	2.96
110	.....do.........	752	629	627	20.66	.310	.309	12,929	14,541	12,762	14,354	1.27	.9902	42,579	50,678	42,162	1.1902	50,181	4,237	5,043	2.48
114	.....do.........	882	805	800	24.23	.396	.394	13,545	14,547	13,392	14,383	.78	.9940	60,906	72,302	60,541	1.1871	71,868	6,024	7,151	3.52
137	Ill. No. 11A...	764	656	631	20.98	.322	.310	12,348	14,293	12,472	14,437	1.37	.9895	55,321	65,201	54,740	1.1786	64,516	5,458	6,432	3.17
138	.....do.........	726	622	596	19.94	.306	.293	12,159	14,320	12,276	14,457	1.48	.9886	51,957	61,294	51,365	1.1797	60,596	5,121	6,041	2.97
139	.....do.........	717	614	597	19.70	.302	.294	12,254	14,269	12,370	14,404	1.09	.9916	52,810	62,279	52,366	1.1793	61,755	5,274	6,219	3.06
141	.....do.........	763	680	652	18.81	.335	.321	12,505	14,336	12,625	14,473	2.05	.9841	38,570	45,505	37,957	1.1798	44,782	5,361	6,325	3.11
111	Ill. No. 11B...	886	742	724	24.35	.365	.356	12,643	14,559	12,659	14,578	1.41	.9891	50,927	60,542	50,372	1.1888	59,882	4,997	5,941	2.93
112	.....do.........	814	663	655	22.36	.326	.323	12,775	14,738	12,593	14,528	1.05	.9919	50,346	59,771	49,938	1.1872	59,286	4,959	5,887	2.90
115	.....do.........	928	791	755	22.89	.389	.372	12,321	14,738	12,145	14,527	1.59	.9878	58,497	69,453	57,783	1.1873	68,606	5,855	6,951	3.42
116	.....do.........	981	851	835	24.19	.419	.411	12,933	14,728	12,748	14,518	.67	.9949	37,562	44,639	37,370	1.1884	44,411	6,177	7,341	3.61
117	.....do.........	965	834	816	23.80	.411	.402	12,537	14,524	12,523	14,508	1.64	.9874	59,837	70,973	59,083	1.1861	70,078	5,850	6,938	3.42
118	.....do.........	939	811	797	23.16	.399	.392	12,801	14,628	12,742	14,560	1.52	.9883	57,077	67,573	56,409	1.1839	66,783	5,697	6,746	3.32
119	.....do.........	1,041	918	899	25.70	.452	.443	13,079	14,780	12,897	14,574	.84	.9935	65,035	77,144	64,612	1.1862	76,643	6,416	7,611	3.75

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds).						Calorific value of fuel per pound (B. t. u.).				Quality of steam (per cent).		Water evaporation.							
			Combustible determined from—			Combustible per sq. ft. of water-heating surface determined from—		By oxygen calorimeter.		By analysis.				Water fed to boiler (pounds).					Per hour (pounds).		
																				Equivalent from and at 212° F.	
		Dry.	Actual w'ght of ash.	Analyses of ash and coal.	Dry per sq. ft. of grate area.	Actual weight of ash.	Analysis of ash.	Dry fuel.	Combustible.	Dry fuel.	Combustible.	Moisture.	Factor of correction (dry steam-unity).	Total weight.	Equivalent from and at 212° F.	Actually corrected for quality of steam (lbs.).	Factor.	Equivalent converted into dry steam from and at 212° F. (lbs.).	Corrected for quality of steam.	Total.	Per sq. ft. of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
120	Ill. No. 11C...	925	827	825	25.41	0.407	0.406	13,370	14,572	13,244	14,435	0.98	0.9925	61,084	72,275	60,626	1.1882	71,733	6,093	7,210	3.55
312	.....do.........	786	702	703	19.38	.346	.346	13,361	14,647	13,241	14,515	1.37	.9894	20,877	25,299	20,656	1.2118	25,031	5,706	6,915	3.40
127	Ill. No. 12.....	872	737	709	21.49	.363	.349	11,963	14,349	11,828	14,187	2.03	.9841	58,952	69,398	58,014	1.1772	68,294	5,784	6,809	3.35
128	.....do.........	870	753	724	21.45	.371	.356	12,154	14,341	12,015	14,177	1.21	.9907	61,268	72,284	60,698	1.1798	71,611	6,040	7,126	3.51
131	.....do.........	760	613	580	20.87	.302	.286	11,709	14,413	11,462	14,109	1.85	.9857	50,884	59,921	50,156	1.1776	59,064	5,016	5,906	2.91
133	.....do.........	834	687	658	22.91	.338	.324	11,849	14,296	11,713	14,132	1.17	.9910	54,944	64,790	54,449	1.1792	64,206	5,429	6,401	3.15
135	.....do.........	840	740	736	23.09	.364	.362	13,104	14,607	12,904	14,384	.76	.9942	62,810	74,160	62,446	1.1807	73,730	6,226	7,350	3.62
136	.....do.........	756	615	599	20.77	.303	.295	11,867	14,363	11,740	14,210	1.37	.9894	49,027	57,993	48,507	1.1788	57,180	5,011	5,907	2.91
463	Ill. No. 12B....	757	662	661	18.67	.326	.325	12,859	14,479	12,695	14,295	.14	.9989	53,972	65,268	53,913	1.2098	65,197	5,375	6,500	3.20
132	Ill. No. 13.....	808	684	674	22.06	.337	.332	12,528	14,473	12,440	14,371	1.20	.9908	56,485	68,954	57,947	1.1790	68,319	5,806	6,845	3.37
134	.....do.........	821	707	700	22.55	.348	.345	12,667	14,432	12,586	14,340	.98	.9925	58,936	69,515	58,494	1.1796	68,994	5,838	6,885	3.39
144	.....do.........	828	740	746	20.42	.364	.367	13,261	14,472	13,181	14,385	1.47	.9887	57,819	68,093	57,165	1.1777	67,322	6,387	7,522	3.70
145	.....do.........	733	671	662	20.14	.330	.326	13,306	14,468	13,225	14,379	.87	.9933	44,788	52,704	44,488	1.1768	52,353	5,830	6,861	3.38
123	Ill. No. 14.....	859	731	702	23.60	.360	.346	12,008	14,184	11,900	14,056	1.41	.9892	53,874	63,361	53,292	1.1761	62,677	5,356	6,299	3.10
125	.....do.........	825	706	691	20.30	.348	.340	12,125	14,146	12,110	14,129	1.90	.9854	53,118	62,599	52,342	1.1785	61,685	5,303	6,250	3.08
130	.....do.........	877	773	763	21.63	.381	.376	12,731	14,311	12,685	14,259	1.61	.9876	57,553	67,930	56,839	1.1803	67,087	5,730	6,763	3.33
126	Ill. No. 15.....	829	694	665	20.44	.342	.327	11,749	14,176	11,545	13,930	2.41	.9811	54,008	63,632	52,982	1.1783	62,429	5,363	6,319	3.11
152	.....do.........	796	706	709	19.63	.347	.349	13,104	14,486	12,804	14,145	1.56	.9880	58,895	69,366	58,188	1.1778	68,534	5,801	6,833	3.36
150	Ill. No. 16.....	796	711	694	19.63	.350	.341	12,874	14,507	12,778	14,399	1.98	.9847	46,951	55,266	46,233	1.1771	54,421	6,140	7,227	3.56
140	Ill. No. 18.....	674	593	586	18.51	.292	.288	12,951	14,472	12,755	14,253	1.37	.9895	49,774	59,669	49,251	1.1787	58,052	4,925	5,805	2.86
148	.....do.........	765	676	666	18.86	.333	.328	12,991	14,572	12,701	14,348	2.83	.9780	52,772	62,134	51,611	1.1774	60,767	5,161	6,077	2.99

147	.....do.........	711	637	642	19.53	.314	.316	13,554	14,541	13,417	14,394	.80	.9938	53,999	63,369	53,664	1.1739	62,996	5,393	6,331	3.15
149	.....do.........	723	640	663	17.83	.315	.326	13,432	14,421	13,435	14,424	1.26	.9903	30,458	35,892	30,158	1.1786	35,544	5,669	6,681	3.29
160	Ill. No. 19A....	749	673	660	18.47	.331	.325	13,036	14,396	12,938	14,288	2.11	.9837	53,961	63,577	53,081	1.1782	62,540	5,298	6,241	3.07
161	.....do.........	721	631	624	17.77	.311	.307	12,911	14,385	12,825	14,290	1.63	.9874	54,325	64,065	53,641	1.1793	63,258	5,380	6,345	3.12
162	.....do.........	843	758	748	20.79	.373	.368	13,068	14,397	12,976	14,295	1.76	.9864	62,343	73,465	61,495	1.1784	72,466	6,162	7,261	3.57
170	.....do.........	736	646	640	20.22	.318	.315	12,857	14,392	12,769	14,294	.99	.9924	49,082	57,603	48,709	1.1736	57,165	5,370	6,308	3.10
171	.....do.........	731	644	638	20.08	.314	.317	12,917	14,397	12,829	14,299	1.32	.9898	56,355	66,104	55,779	1.1730	65,429	5,594	6,563	3.23
175	Ill. No. 19B...	833	725	720	20.54	.357	.355	13,005	14,683	13,102	14,793	.74	.9943	64,328	75,521	63,961	1.1740	75,090	6,461	7,585	3.73
204	.....do.........	753	683	657	20.69	.336	.323	13,050	14,660	13,144	14,765	.44	.9966	60,750	71,600	60,543	1.1786	71,356	6,036	7,114	3.50
205	.....do.........	742	660	635	20.38	.325	.313	13,001	14,675	13,093	14,779	.98	.9925	58,345	68,777	57,907	1.1788	68,261	5,832	6,874	3.38
420	Ill. No. 19C....	809	709	680	19.95	.349	.335	12,431	14,364	12,580	14,537	1.36	.9895	58,785	68,931	58,168	1.1726	68,208	5,799	6,800	3.35
423	.....do.........	687	596	579	16.94	.293	.285	12,496	14,370	12,645	14,541	1.16	.9911	50,662	59,345	50,211	1.1714	58,817	5,006	5,864	2.89
424	Ill. No. 19D...	757	663	646	18.67	.326	.318	12,416	14,229	11,963	13,710	1.16	.9911	55,632	65,178	55,137	1.1716	64,599	5,514	6,460	3.18
425	.....do.........	784	687	668	19.33	.338	.329	12,460	14,229	12,002	13,706	1.21	.9907	58,132	68,067	57,591	1.1709	67,433	5,759	6,743	3.32
421	Ill. No. 19E...	789	692	674	19.46	.341	.332	12,454	14,215	12,001	13,698	1.24	.9905	57,587	67,567	57,040	1.1733	66,925	5,704	6,693	3.30
422	.....do.........	789	696	675	19.46	.343	.332	12,578	14,347	12,222	13,941	1.13	.9913	59,643	69,925	59,124	1.1724	69,317	5,871	6,884	3.39
292	Ill. No. 20.....	628	506	500	15.49	.249	.246	11,425	13,953	11,281	13,777	1.87	.9895	39,358	47,607	38,945	1.2096	47,108	3,974	4,807	2.37
301	.....do.........	896	799	763	24.61	.393	.375	12,506	14,294	12,209	13,955	.62	.9958	59,473	71,915	59,193	1.2092	71,576	5,949	7,194	3.54
302	.....do.........	935	843	808	25.69	.415	.398	12,548	14,308	12,254	13,968	.94	.9928	57,914	70,261	57,497	1.2132	69,755	6,374	7,733	3.81
315	Ill. No. 21.....	813	713	667	20.05	.351	.328	11,945	14,251	11,576	13,811	.91	.9930	26,857	32,626	26,669	1.2148	32,397	5,465	6,639	3.27
316	.....do.........	813	710	679	20.05	.350	.334	12,240	14,302	11,855	13,853	2.30	.9822	54,469	66,093	53,499	1.2134	64,916	5,334	6,472	3.19
318	.....do.........	1,026	897	889	25.30	.442	.438	12,469	14,185	12,155	13,828	1.18	.9909	50,720	61,554	50,258	1.2136	60,993	6,885	8,355	4.11
324	Ill. No. 22A....	936	803	753	23.08	.395	.371	11,484	13,978	11,263	13,709	2.12	.9836	60,735	73,769	59,739	1.2146	72,559	6,016	7,307	3.60
325	.....do.........	917	796	761	22.61	.392	.375	11,876	14,043	11,614	13,733	1.00	.9923	60,675	73,702	60,208	1.2147	73,135	6,021	7,313	3.60
328	.....do.........	1,084	965	963	26.73	.475	.474	12,924	14,296	12,715	14,065	.86	.9934	72,414	87,903	71,936	1.2139	87,323	7,266	8,821	4.34
306	Ill. No. 23A....	750	650	619	18.50	.320	.305	11,759	13,954	11,756	13,950	1.08	.9917	47,799	57,928	47,402	1.2119	57,446	5,043	6,111	3.01
317	.....do.........	796	715	704	19.63	.352	.347	12,794	14,279	12,712	14,188	2.27	.9824	44,615	54,154	43,830	1.2138	53,201	5,398	6,552	3.23
321	Ill. No. 23B....	963	870	861	23.75	.428	.424	12,996	14,397	12,370	13,703	.84	.9935	28,015	34,002	27,833	1.2137	33,781	6,326	7,677	3.78
322	.....do.........	995	898	890	24.54	.442	.438	12,996	14,397	12,370	13,703	2.15	.9834	23,597	28,666	23,205	1.2148	28,189	6,358	7,723	3.80
335	Ill. No. 24B...	831	723	706	20.49	.356	.348	12,245	14,120	12,170	14,034	.87	.9933	53,709	64,972	53,349	1.2097	64,536	5,546	6,709	3.30
336	.....do.........	871	734	745	21.48	.361	.367	12,623	14,230	12,551	14,148	1.14	.9912	33,734	40,801	33,437	1.2095	40,442	5,527	6,685	3.29
337	.....do.........	958	798	823	23.63	.393	.405	12,474	14,193	12,404	14,113	1.15	.9911	25,117	30,369	24,893	1.2091	30,098	6,416	7,757	3.82
338	Ill. No. 25A and 25B.....	866	720	726	21.36	.355	.357	12,519	14,439	12,244	14,122	1.91	.9853	51,116	61,850	50,365	1.2100	60,942	5,208	6,302	3.10
339	.....do.........	958	805	782	23.63	.396	.385	12,022	14,242	11,758	13,930	1.57	.9879	60,053	72,688	59,326	1.2104	71,808	5,933	7,181	3.54
341	Ill. No. 26.....	761	634	621	20.91	.312	.306	12,029	14,177	11,889	14,012	2.00	.9845	48,588	58,646	47,835	1.2070	57,737	4,784	5,774	2.84
342	.....do.........	838	690	692	23.02	.340	.341	12,260	14,312	12,116	14,144	1.66	.9872	47,595	57,704	46,986	1.2124	56,966	5,297	6,422	3.16
353	Ill. No. 27.....	804	694	660	19.83	.342	.325	11,831	14,150	11,610	13,886	1.93	.9851	53,302	64,693	52,508	1.2137	63,729	5,251	6,373	3.14
354	.....do.........	781	664	636	19.26	.327	.313	11,713	14,039	11,489	13,771	.96	.9926	52,030	63,180	51,645	1.2143	62,713	5,154	6,259	3.08
459	Ill. No. 28A....	759	660	648	18.72	.325	.319	12,557	14,447	12,514	14,397	.13	.9990	52,408	63,251	52,356	1.2069	63,188	5,262	6,351	3.13
457	Ill. No. 28B....	805	700	687	19.85	.345	.338	12,839	14,522	12,749	14,420	.19	.9986	52,898	63,530	52,824	1.2010	63,442	5,786	6,949	3.42
448	Ill. No. 28C....	913	805	789	22.52	.396	.388	12,920	14,532	12,798	14,394	2.19	.9831	67,483	80,386	66,343	1.1912	79,028	6,614	7,879	3.88
452	.....do.........	891	785	773	21.97	.387	.381	13,070	14,564	12,942	14,422	.28	.9979	66,798	80,244	66,658	1.2013	80,076	6,666	8,008	3.94
465	Ill. No. 29A....	825	740	744	20.35	.364	.366	13,120	14,318	12,847	14,021	.13	.9990	60,828	73,474	60,767	1.2079	73,400	6,089	7,355	3.62
460	Ill. No. 29B....	867	738	706	21.38	.363	.348	11,945	14,188	11,542	13,709	.13	.9990	58,110	70,220	58,052	1.2084	70,150	5,776	6,980	3.44
461	.....do.........	905	814	788	22.32	.401	.388	12,728	14,372	12,298	13,887	.07	.9995	33,863	40,944	33,846	1.2091	40,923	6,245	7,550	3.72
466	.....do.........	905	801	789	22.32	.394	.388	12,762	14,476	12,535	14,218	.16	.9988	66,005	79,793	65,926	1.2089	79,698	6,547	7,914	3.90
511	Ill. No. 30.....	849	772	761	20.94	.380	.375	13,271	14,617	12,805	14,104	.29	.9978	51,729	62,747	51,615	1.2130	62,609	6,016	7,297	3.59
489	Ill. No. 31.....	858	732	722	21.16	.360	.355	12,303	14,379	12,325	14,405	.29	.9978	55,493	67,185	55,371	1.2107	67,038	5,847	7,079	3.49
491	.....do.........	878	743	741	21.65	.366	.365	12,335	14,388	12,069	14,078	.29	.9978	58,442	70,744	58,313	1.2105	70,588	5,981	7 240	3.56
513	Ill. No. 33.....	1,071	790	770	26.41	.389	.379	11,099	14,486	10,640	13,887	.31	.9976	47,126	57,145	47,013	1.2126	57,008	5,416	6,568	3.23
509	Ill. No. 34B....	872	782	786	21.50	.385	.387	13,621	14,847	13,181	14,368	.33	.9975	57,136	69,403	56,993	1.2147	69,229	6,333	7,692	3.79
71	Ind. No. 1.....	880	812	811	21.70	.400	.399	13,635	14,672	13,500	14,527	.51	.9961	42,122	50,871	41,958	1.2077	50,673	6,357	7,678	3.78

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds).						Calorific value of fuel per pound (B. t. u.).				Quality of steam (per cent).		Water evaporation.							
		Dry.	Combustible determined from—		Dry per sq. ft. of grate area.	Combustible per sq. ft. of water-heating surface determined from—		By oxygen calorimeter		By analysis.		Moisture.	Factor of correction (dry steam=unity).	Water fed to boiler (pounds).		Actually corrected for quality of steam (lbs.).	Factor.	Equivalent converted into dry steam from and at 212° F. (lbs.).	Per hour (pounds).		
			Actual w'ght of ash.	Analyses of ash and coal.		Actual weight of ash.	Analysis of ash.	Dry fuel.	Combustible.	Dry fuel.	Combustible.			Total weight.	Equivalent from and at 212° F.				Corrected for quality of steam.	Equivalent from and at 212° F. Total.	Equivalent from and at 212° F. Per sq. ft. of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
68	Ind. No. 1	908	827	807	22.39	0.407	0.397	13,377	14,768	13,145	14,507	0.71	0.9946	63,552	76,745	63,208	1.2076	76,330	6,363	7,684	3.78
65	Ind. No. 2	832	732	701	20.51	.360	.345	12,452	14,428	12,463	14,441	1.12	.9916	56,482	68,208	56,005	1.2076	67,632	5,527	6,674	3.29
162	Ind. No. 3	813	679	650	20.05	.334	.320	11,669	14,095	11,641	14,061	2.28	.9824	54,997	64,736	54,029	1.1780	63,646	5,599	6,595	3.25
151	Ind. No. 4	756	632	612	18.64	.311	.300	11,977	14,356	11,849	14,202	2.20	.9830	50,823	59,834	49,959	1.1778	58,817	4,971	5,852	2.88
165	.....do	800	666	618	21.98	.328	.304	11,486	14,363	11,367	14,214	.96	.9926	55,360	65,109	54,950	1.1761	64,617	5,479	6,442	3.17
166	.....do	714	563	549	19.62	.277	.270	11,693	14,345	11,569	14,193	1.60	.9877	41,109	48,233	40,603	1.1733	47,639	4,614	5,414	2.67
154	.....do	779	711	700	19.21	.350	.345	13,421	14,658	13,086	14,293	.92	.9929	58,714	69,188	58,297	1.1784	68,697	5,859	6,904	3.40
153	Ind. No. 5	779	685	667	19.21	.337	.328	12,564	14,351	12,465	14,240	1.18	.9909	55,104	64,885	54,603	1.1775	64,295	5,449	6,417	3.16
155	.....do	706	616	594	17.41	.303	.292	12,546	14,459	12,398	14,283	1.50	.9885	50,500	59,499	49,919	1.1782	58,815	5,002	5,898	2.90
156	.....do	776	676	664	19.14	.333	.327	12,730	14,517	12,574	14,339	1.37	.9894	53,631	63,226	53,063	1.1789	62,556	5,340	6,306	3.10
157	Ind. No. 6	754	643	633	18.59	.317	.312	12,505	14,585	12,538	14,623	2.04	.9842	52,911	62,340	52,075	1.1782	61,355	5,223	6,154	3.03
159	.....do	868	781	763	21.40	.384	.376	13,091	14,684	13,169	14,772	1.62	.9875	59,701	70,352	58,955	1.1784	69,472	5,943	7,003	3.45
158	Ind. No. 7A	805	724	714	19.85	.356	.351	13,248	14,669	13,270	14,694	.99	.9924	60,165	70,862	59,708	1.1778	70,324	5,959	7,018	3.45
288	.....do	704	629	610	19.34	.310	.300	13,077	14,673	13,019	14,608	1.14	.9912	49,979	60,423	49,538	1.2090	59,892	5,065	6,124	3.02
164	Ind. No. 7B	692	606	594	19.01	.298	.294	12,838	14,496	12,767	14,416	1.36	.9895	47,003	55,440	46,509	1.1795	54,857	4,637	5,469	2.69
176	.....do	709	630	611	17.48	.310	.300	12,710	14,474	12,634	14,388	1.67	.9872	49,395	58,064	48,763	1.1755	57,321	4,842	5,692	2.80
182	Ind. No. 8	802	712	686	19.78	.351	.338	12,838	14,680	12,785	14,620	.92	.9929	55,940	65,608	55,548	1.1739	65,202	5,565	6,583	3.22
183	.....do	699	613	593	17.24	.302	.292	12,587	14,636	12,537	14,578	1.65	.9873	50,276	59,180	49,637	1.1771	58,428	4,964	5,843	2.88
185	.....do	796	691	670	19.63	.340	.330	12,622	14,735	12,575	14,680	.99	.9924	55,252	64,998	54,832	1.1764	64,504	5,483	6,450	3.18
184	.....do	802	716	707	19.78	.353	.348	13,091	14,633	13,223	14,781	.71	.9945	60,151	70,647	59,820	1.1745	70,259	5,962	7,028	3.46

168	Ind. No. 9A	869	751	723	23.87	.370	.356	12,181	14,363	12,170	14,350	.74	.9943	62,470	73,309	62,113	1.1735	72,890	6,259	7,348	3.62
169	....do	769	664	651	21.13	.327	.321	12,447	14,414	12,431	14,395	.82	.9937	56,912	66,849	56,553	1.1746	66,426	5,644	6,629	3.26
174	Ind. No. 9B	778	684	671	19.19	.337	.330	12,740	14,498	12,645	14,390	1.15	.9911	36,720	43,065	36,393	1.1728	42,682	5,432	6,370	3.14
334	Ind. No. 9A and 9B	968	854	843	23.87	.420	.415	12,798	14,458	12,564	14,193	1.09	.9916	26,672	32,330	26,448	1.2121	32,058	6,747	8,178	4.03
167	Ind. No. 10	832	737	720	22.85	.363	.354	12,866	14,515	12,797	14,437	.75	.9943	62,020	72,818	61,666	1.1741	72,402	6,136	7,204	3.55
177	....do	985	872	859	23.05	.429	.423	13,595	14,620	13,523	14,542	1.36	.9895	65,590	77,134	64,901	1.1760	76,324	6,490	7,632	3.76
233	Ind. No. 11	830	743	744	22.80	.366	.366	13,423	14,746	13,056	14,342	.66	.9949	60,172	72,032	59,865	1.1971	71,664	6,204	7,426	3.66
234	....do	736	668	658	20.22	.329	.324	13,333	14,733	12,965	14,326	.80	.9939	53,495	64,066	53,169	1.1976	63,675	5,527	6,619	3.26
235	....do	771	708	696	21.18	.349	.343	13,473	14,775	13,097	14,362	.66	.9949	58,170	69,676	57,873	1.1978	69,320	5,816	6,967	3.43
299	Ind. No. 12	837	713	689	22.99	.351	.339	12,116	14,450	11,923	14,219	1.00	.9923	56,673	68,506	56,237	1.2088	67,979	5,579	6,744	3.32
300	....do	915	788	751	25.13	.388	.370	12,130	14,410	11,936	14,179	.87	.9933	62,940	76,151	62,518	1.2099	75,641	6,220	7,526	3.71
310	....do	772	686	689	19.04	.338	.339	13,271	14,601	13,073	14,383	1.70	.9869	56,160	68,066	55,424	1.2120	67,174	5,846	7,086	3.49
432	Ind. No. 13	807	694	678	19.90	.342	.334	12,497	14,508	12,452	14,456	1.21	.9907	60,178	70,601	59,618	1.1732	69,944	5,914	6,939	3.42
433	....do	832	682	688	20.52	.336	.339	12,577	14,543	12,530	14,489	1.29	.9901	21,544	25,278	21,331	1.1738	25,028	5,688	6,674	3.29
430	Ind. No. 14	766	643	628	18.89	.317	.309	11,986	14,223	11,824	14,031	1.09	.9916	52,341	61,548	51,901	1.1759	61,030	5,282	6,152	3.08
431	....do	783	651	588	19.31	.321	.290	11,021	14,171	10,877	13,986	1.34	.9897	52,718	61,928	52,175	1.1747	61,290	5,218	6,129	3.02
428	Ind. No. 15	816	728	713	20.12	.358	.351	13,099	14,580	12,856	14,310	1.00	.9923	57,682	67,736	57,238	1.1743	67,215	5,901	6,929	3.41
429	....do	741	662	654	18.27	.326	.322	13,207	14,584	12,947	14,297	1.16	.9911	54,934	64,547	54,445	1.1750	63,973	5,417	6,365	3.13
426	Ind. No. 16	781	679	656	19.26	.334	.323	12,350	14,319	12,218	14,166	1.27	.9902	55,727	65,390	55,181	1.1734	64,749	5,502	6,456	3.18
427	....do	699	604	586	17.24	.297	.289	12,328	14,370	12,197	14,217	1.37	.9894	44,107	51,796	43,639	1.1743	51,245	4,849	5,694	2.80
441	Ind. No. 17	795	690	689	19.61	.340	.339	12,929	14,342	12,694	14,081	2.88	.9777	55,721	66,369	54,478	1.1911	64,889	5,514	6,568	3.23
442	....do	729	609	606	17.98	.300	.298	12,524	14,320	12,289	14,051	2.46	.9810	49,139	58,495	48,205	1.1904	57,383	4,759	5,665	2.79
435	Ind. No. 18B	830	747	745	20.47	.368	.367	13,545	14,721	13,172	14,316	2.52	.9805	63,901	75,691	62,655	1.1845	74,215	6,203	7,348	3.62
436	....do	886	795	791	21.85	.391	.399	13,617	14,755	13,250	14,357	1.95	.9850	65,898	78,010	64,910	1.1838	76,840	6,713	7,946	3.91
464	Ind. No. 19	846	737	692	20.86	.363	.341	11,930	14,401	11,281	13,618	.11	.9992	41,719	50,392	41,686	1.2079	50,353	5,507	6,652	3.28
10	Ind. T. No. 1	778	664	639	19.17	.327	.314	12,834	14,767	12,728	14,645	.64	.9951	55,570	65,845	55,298	1.1849	65,524	5,672	6,720	3.31
20	Ind. T. No. 2	872	767	762	21.50	.377	.375	13,414	14,929	13,307	14,810	.41	.9968	63,370	74,929	63,167	1.1824	74,689	6,211	7,344	3.62
417	Ind. T. No. 2 B	722	630	618	17.81	.310	.304	13,534	15,061	13,448	14,966	.75	.9943	57,159	66,990	56,833	1.1720	66,608	5,599	6,562	3.23
418	....do	734	650	646	18.10	.320	.318	13,721	15,042	13,626	14,938	.75	.9943	59,343	69,538	59,005	1.1718	69,142	5,871	6,880	3.39
455	....do	807	710	712	19.90	.350	.351	13,957	15,217	13,734	14,974	.27	.9979	56,124	67,349	56,006	1.2000	67,207	5,646	6,775	3.34
453	....do	808	711	705	19.93	.350	.347	13,687	14,973	13,639	14,921	.28	.9979	63,871	76,728	63,737	1.2013	76,567	6,342	7,619	3.75
456	....do	867	781	772	21.38	.385	.380	13,856	15,135	13,626	14,884	.25	.9981	65,109	77,975	64,985	1.1976	77,826	6,447	7,721	3.80
32	Ind. T. No. 3	869	732	744	21.43	.360	.366	13,005	14,588	12,780	14,335	.59	.9955	60,141	71,496	59,769	1.1888	71,173	5,977	7,105	3.50
52	Ind. T. No. 4	853	751	719	21.04	.370	.354	12,027	13,961	11,968	13,892	.90	.9931	55,213	66,073	54,830	1.1967	65,615	5,367	6,422	3.16
437	Ind. T. No. 8	783	681	690	19.31	.335	.340	13,932	15,140	13,466	14,634	2.74	.9788	44,718	52,960	43,770	1.1843	51,837	5,875	6,958	3.43
449	Ind. T. No. 9	755	661	662	18.62	.325	.326	14,682	15,730	14,891	15,954	.39	.9970	59,021	70,625	58,844	1.1966	70,413	5,873	7,027	3.46
450	....do	749	......	667	18.47	......	.328	14,602	15,817	14,542	15,752	.30	.9977	61,771	74,002	61,629	1.1980	73,832	6,181	7,405	3.65
45	Iowa No. 1	942	755	728	23.23	.372	.358	11,443	14,320	11,257	14,087	.65	.9950	57,373	68,675	57,086	1.1970	68,332	5,690	6,822	3.36
67	Iowa No. 2	944	779	736	23.28	.383	.363	11,497	14,162	11,444	14,097	.91	.9930	55,030	66,394	54,645	1.2065	65,929	5,510	6,648	3.27
49	Iowa No. 3	931	788	726	22.96	.388	.357	11,671	14,210	11,605	14,130	.98	.9925	55,107	66,035	54,694	1.1983	65,540	5,451	6,532	3.22
47	Iowa No. 4	812	682	645	20.02	.336	.318	11,678	14,157	11,545	13,996	1.27	.9903	48,765	58,289	48,292	1.1953	57,723	4,829	5,772	2.84
66	....do	856	738	705	21.11	.364	.348	12,546	14,641	12,749	14,878	.84	.9936	53,558	64,270	53,215	1.2000	63,858	5,304	6,365	3.13
55	Iowa No. 5	942	809	771	23.23	.398	.380	11,963	14,233	11,848	14,096	1.00	.9924	59,083	71,065	58,632	1.2028	70,523	5,873	7,064	3.48
601	Jamest'n No. 1	735	627	607	......	.309	.299	12,911	15,357	12,711	15,120	1.30	.9900	45,840	53,793	45,382	1.1735	53,256	5,678	6,667	3.28
602	....do	887	767	724	......	.378	.356	12,607	15,165	12,663	15,233	.40	.9969	51,616	60,938	51,456	1.1806	60,749	6,353	7,500	3.69
603	Jamest'n No. 3	879	825	797	......	.406	.392	14,555	15,852	14,787	16,104	.78	.9940	58,226	68,258	57,877	1.1723	67,849	7,128	8,356	4.11
604	....do	921	867	826	......	.427	.407	14,353	15,812	......	......	.61	.9953	63,090	74,497	62,793	1.1808	74,146	7,849	9,268	4.56
605	....do	813	758	735	......	.373	.362	14,423	15,851	......	......	.79	.9939	54,180	63,954	53,850	1.1804	63,565	6,530	7,705	3.79
606	....do	556	507	505	13.71	.262	.261	14,769	15,838	......	......	3.04	.9766	44,318	52,300	43,281	1.1801	51,076	4,809	5,675	2.94
607	....do	559	511	517	13.79	.265	.268	15,019	15,829	......	......	2.00	.9845	45,540	53,792	44,834	1.1812	52,958	4,943	5,839	3.02
608	Jamest'n No. 4	600	565	557	14.80	.292	.288	14,891	15,680	......	......	2.00	.9845	45,600	53,872	44,893	1.1814	53,037	4,972	5,873	3.04

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds).						Calorific value of fuel per pound (B. t. u.).				Quality of steam (per cent).		Water evaporation.							
		Dry.	Combustible determined from—		Dry per sq. ft. of grate area.	Combustible per sq. ft. of water-heating surface determined from—		By oxygen calorimeter.		By analysis.		Moisture.	Factor of correction (dry steam-unity).	Water fed to boiler (pounds).		Actually corrected for quality of steam (lbs.).	Factor.	Equivalent converted into dry steam from and at 212° F. (lbs.).	Per hour (pounds).		
			Actual w'ght of ash.	Analyses of ash and coal.		Actual weight of ash.	Analysis of ash.	Dry fuel.	Combustible.	Dry fuel.	Combustible.			Total weight.	Equivalent from and at 212° F.				Corrected for quality of steam.	Equivalent from and at 212° F. Total.	Equivalent from and at 212° F. Per sq. ft. of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
609	Jamest'n No. 4.	958	......	888	23.63	......	0.460	14,843	15,720	......	......	1.10	0.9915	38,854	46,166	38,524	1.1882	45,774	7,894	9,380	4.85
610	....do....	1,119	1,062	1,038	27.60	0.550	.537	14,796	15,735	......	......	.89	.9932	85,830	101,949	85,246	1.1878	101,255	9,440	11,213	5.81
611	....do....	396	376	379	......	.185	.187	15,113	15,743	......	......	.70	.9946	31,847	37,806	31,675	1.1871	37,601	3,519	4,178	2.06
612	....do....	414	394	394	......	.194	.194	14,976	15,738	......	......	.70	.9946	32,493	38,615	32,318	1.1884	38,407	3,591	4,267	2.10
613	....do....	421	400	385	......	.197	.190	14,418	15,737	......	......	.65	.9950	30,994	36,957	30,839	1.1925	36,772	3,427	4,086	2.01
614	....do....	376	358	349	......	.176	.172	14,650	15,765	......	......	.66	.9949	30,141	35,907	29,987	1.1913	35,724	3,332	3,969	1.95
615	....do....	489	464	460	......	.228	.226	14,825	15,733	......	......	.83	.9936	38,913	46,408	38,664	1.1926	46,110	4,296	5,123	2.52
616	....do....	531	505	506	......	.249	.249	15,003	15,743	......	......	.78	.9940	41,690	49,707	41,440	1.1923	49,409	4,604	5,490	2.70
617	....do....	482	448	462	......	.221	.227	15,115	15,748	......	......	.86	.9934	39,245	46,953	38,986	1.1964	46,643	4,322	5,172	2.55
618	....do....	469	436	443	......	.215	.218	14,884	15,749	......	......	.86	.9934	35,784	42,866	35,548	1.1979	42,583	4,444	5,323	2.62
619	....do....	497	461	475	......	.227	.234	15,071	15,751	......	......	.89	.9932	41,080	49,108	40,801	1.1954	48,774	4,533	5,419	2.67
627	Jamest'n No. 6.	894	845	845	......	.416	.416	14,936	15,757	......	......	1.23	.9905	71,893	86,595	71,210	1.2045	85,772	7,912	9,530	4.69
630	....do....	570	538	538	......	.265	.265	14,954	15,783	......	......	1.16	.9911	45,390	54,654	44,986	1.2041	54,168	4,998	6,019	2.96
631	....do....	1,209	1,139	1,139	......	.561	.561	14,972	15,780	......	......	1.65	.9873	95,735	115,275	94,519	1.2041	113,810	10,526	12,674	6.24
620	Jamest'n No. 7.	636	605	605	......	.298	.298	15,059	15,806	......	......	.93	.9929	50,607	60,561	50,248	1.1967	60,132	5,743	6,872	3.38
621	....do....	682	649	649	......	.320	.320	15,057	15,801	......	......	.95	.9927	50,948	61,076	50,576	1.1988	60,631	5,620	6,737	3.32
623	....do....	872	821	821	......	.404	.404	14,900	15,792	......	......	.94	.9928	68,978	82,746	68,481	1.1996	82,150	7,609	9,128	4.49
624	....do....	938	894	894	......	.440	.440	15,055	15,791	......	......	1.06	.9918	30,311	36,428	30,062	1.2018	36,129	7,516	9,032	4.45
625	....do....	711	669	669	......	.329	.329	14,863	15,771	......	......	1.12	.9914	51,145	61,394	50,705	1.2004	60,866	6,338	7,608	3.75
626	....do....	901	853	853	......	.420	.420	14,929	15,763	......	......	1.18	.9909	60,900	73,263	60,346	1.2030	72,596	7,409	8,985	4.42
639	Jamest'n No. 11	719	681	664	17.73	.352	.343	14,931	15,921	......	......	1.64	.9874	56,164	67,860	55,456	1.2084	67,014	6,128	7,406	3.83

6	Kans. No. 1....	673	600	568	16.60	.295	.280	13,307	15,043	13,385	15,131	3.02	.9766	47,861	56,432	46,741	1.1791	55,112	4,628	5,457	2.60
7	.....do.........	735	631	607	18.13	.310	.299	12,694	14,874	12,737	14,925	2.59	.9800	53,149	62,812	52,086	1.1818	61,555	5,370	6,346	3.13
5	Kans. No. 2....	767	677	......	18.90	.334	....	12,150	14,948	12,019	14,782	2.89	.9775	38,062	44,837	37,206	1.1780	43,829	5,315	6,261	3.08
13	.....do.........	814	726	712	20.08	.357	.350	13,968	15,878	13,811	15,205	.48	.9968	57,706	68,260	57,498	1.1829	68,007	6,130	7,250	3.57
488	Kans. No. 2 B..	802	695	686	22.00	.342	.338	11,767	14,969	12,346	15,705	.27	.9979	44,601	53,972	44,507	1.2101	53,858	5,780	6,995	3.44
487	.....do.........	788	634	622	19.43	.312	.306	12,193	15,040	12,065	14,891	.34	.9974	50,138	60,822	50,008	1.2181	60,665	5,182	6,287	3.10
495	.....do.........	823	745	734	20.80	.367	.361	13,811	15,184	13,349	14,676	.34	.9974	62,230	75,373	62,068	1.2112	75,177	6,386	7,734	3.81
3	Kans. No. 3....	761	656	635	18.77	.323	.313	13,010	15,082	12,985	15,055	3.80	.9701	50,879	59,788	49,358	1.1750	57,996	4,981	5,853	2.88
4	.....do.........	667	580	554	16.45	.286	.273	13,194	15,120	13,216	15,137	2.90	.9773	46,494	54,612	45,439	1.1746	53,373	4,369	5,133	2.53
58	Kans. No. 4....	737	634	601	18.18	.312	.296	12,397	14,659	12,375	14,633	1.38	.9895	48,097	57,981	47,592	1.2055	57,372	4,736	5,709	2.81
72	Kans. No. 5....	836	734	706	20.62	.361	.347	13,144	15,013	13,057	14,914	.48	.9964	60,917	73,764	60,698	1.2109	73,499	6,131	7,424	3.66
311	Kans. No. 6....	755	623	602	18.62	.307	.296	12,343	14,859	12,278	14,780	1.49	.9885	49,569	60,107	48,999	1.2126	59,416	4,910	5,954	2.93
323	.....do.........	906	771	779	22.34	.380	.384	13,135	14,897	13,144	14,908	.88	.9932	46,129	55,996	45,815	1.2139	55,615	6,363	7,724	3.80
60	Ky. No. 1......	809	746	737	19.95	.367	.363	14,364	15,295	14,128	15,044	.55	.9969	61,204	73,728	61,011	1.2046	73,495	6,081	7,825	3.61
255	Ky. No. 1 C...	719	676	666	17.73	.333	.328	14,414	15,303	14,319	15,202	1.70	.9869	45,944	55,294	45,342	1.2085	54,569	5,577	6,712	3.30
263	.....do.........	583	545	528	16.02	.268	.260	14,272	15,284	14,179	15,184	1.05	.9919	47,573	57,535	47,188	1.2094	57,069	4,728	5,718	2.82
265	.....do.........	585	547	536	14.43	.269	.264	14,245	15,288	14,148	15,184	2.38	.9816	32,235	38,943	31,642	1.2081	38,227	4,633	5,597	2.76
57	Ky. No. 2......	882	786	780	21.75	.387	.384	14,374	14,745	13,136	14,483	6.74	.9949	60,092	72,309	59,784	1.2033	71,938	5,978	7,194	3.54
76	.....do.........	887	779	759	21.87	.383	.374	12,767	14,572	12,524	14,295	3,14	.9976	58,226	70,308	58,086	1.2075	70,139	5,917	7,145	3.52
64	Ky. No. 3......	882	791	767	21.75	.389	.379	13,036	14,609	12,890	14,446	.82	.9938	61,486	73,917	61,102	1.2022	73,457	6,070	7,298	3.59
62	Ky. No. 4......	889	773	741	21.90	.381	.364	12,937	14,960	12,647	14,623	.51	.9961	60,590	72,828	60,354	1.2020	72,544	6,076	7,303	3.60
276	Ky. No. 5......	800	772	761	21.98	.380	.375	14,571	15,169	14,238	14,822	.89	.9932	65,753	79,587	65,306	1.2104	79,046	6,677	8,082	3.98
277	Ky. No. 5......	624	587	584	15.39	.289	.288	14,510	15,146	14,177	14,799	2.12	.9836	50,792	61,468	49,959	1.2102	60,460	5,372	6,501	3.20
270	Ky. No. 6......	650	621	621	16.03	.306	.306	14,445	14,933	14,375	14,861	.73	.9944	54,030	65,236	53,727	1.2074	64,870	5,362	6,474	3.19
271	.....do.........	643	619	614	15.86	.305	.302	14.512	14,932	14,447	14,865	1.08	.9917	53,070	64,093	52,630	1.2077	63,561	5,252	6,343	3.12
278	Ky. No. 7......	617	533	523	16.95	.262	.258	12,564	14,455	12,398	14,264	1.02	.9922	43,624	52,781	43,284	1.2099	52,369	4,509	5,455	2.69
279	.....do.........	592	499	493	14.60	.246	.242	12,505	14,468	12,343	14,281	2.96	.9782	38,639	46,730	37,797	1.2094	45,712	4,099	4,958	2.44
434	Ky. No. 8......	797	727	715	19.65	.358	.352	14,026	15,269	13,567	14,769	2.24	.9827	56,546	67,058	55,568	1.1859	65,897	6,106	7,241	3.57
443	.....do.........	816	747	728	20.12	.368	.358	14,044	15,297	13,586	14,798	1.91	.9853	62,474	74,388	61,556	1.1907	73,295	6,333	7,541	3.71
462	Ky. No. 9 B...	871	758	752	21.48	.373	.370	13,084	14,690	12,812	14,384	.08	.9994	62,075	75,036	62,038	1.2088	74,992	6,204	7,499	3.09
222	Md. No. 1......	641	559	548	15.81	.275	.270	13,680	15,681	13,514	15,491	1.86	.9856	49,570	58,929	48,856	1.1888	58,080	4,886	5,808	2.86
231	.....do.........	716	631	623	19.67	.311	.307	13,946	15,691	13,829	15,559	.88	.9932	58,115	69,587	57,720	1,1974	69,114	5,801	6,946	3.42
232	.....do.........	707	627	615	19.42	.309	.303	14,033	15,676	13,910	15,539	.83	.9936	56,579	67,742	56,217	1.1973	67,309	5,639	6,751	3.32
490	Md. No. 2......	816	758	734	20.12	.371	.361	14,515	15,837	14,521	15,844	.32	.9976	65,700	79,655	65,542	1,2124	79,463	6,806	8,252	4.06
493	.....do.........	859	781	774	21.18	.385	.381	14,576	15,843	14,312	15,557	.27	.9979	72,605	87,983	72,453	1.2118	87,799	7,245	8,780	4.32
518	.....do.........	463	390	405	22.81	.192	.199	14,717	15,796	14,798	15,883	.23	.9983	22,169	26,889	22,131	1,2129	26,843	4,083	4,953	2.44
12	Mo. No. 1.......	903	731	701	22.30	.360	.345	12,109	14,867	12,096	14,851	.45	.9966	60,647	71,806	60,441	1.1840	71,562	6,044	7,156	3.52
23	.....do.........	826	696	680	20.37	.343	.335	12,676	14,938	12,595	14,842	.71	.9945	28,522	33,836	28,365	1.1863	33,649	5,562	6,598	3.24
15	.....do.........	840	740	726	20.71	.364	.357	13,171	14,967	13,205	15,006	.38	.9970	60,195	70,976	60,016	1.1791	70,765	6,056	7,141	3.51
37	Mo. No. 2.......	1,014	805	777	25.00	.396	.383	11,500	14,234	11,333	14,028	.71	.9946	60,303	72,098	59,974	1.1956	71,705	6,008	7,183	3.54
44	..... do.........	819	688	637	20.20	.339	.313	11,561	14,292	11,385	14,075	.83	.9936	49,925	59,790	49,605	1.1976	59,407	4,969	5,951	2.93
78	Mo. No. 3.......	886	637	571	21.85	.314	.281	9,535	13,817	9,608	13,922	.67	.9949	42,691	51,579	42,475	1.2082	51,318	4,266	5,158	2.54
77	.....do.........	881	775	758	21.72	.381	.373	12,602	14,102	12,695	14,207	.57	.9957	54,002	65,294	53,767	1.2091	65,010	5,413	6,545	3.22
70	Mo. No. 4.......	837	781	769	20.64	.384	.379	14,197	15,155	14,206	15,164	.64	.9952	61,297	74,090	61,002	1.2087	73,733	6,111	7,386	3.64
319	Mo. No. 5.......	756	625	605	18.64	.308	.298	11,747	14,284	11,686	14,210	1.00	.9923	45,250	54,929	44,902	1.2139	54,507	4,663	5,660	2.79
320	.....do.........	902	757	714	22.24	.373	.352	11,668	14,292	11,610	14,221	1.00	.9923	47,551	57,698	47,185	1.2134	57,254	5,651	6,857	3.38
326	Mo. No. 6.......	885	765	732	21.82	.377	.360	12,155	14,408	12,019	14,247	1.00	.9923	58,085	70,550	57,638	1.2146	70,007	5,810	7,057	3.47
327	.....do.........	935	832	800	23.06	.410	.394	12,677	14,555	12,537	14,394	1.00	.9923	61,906	75,216	61,429	1.2150	74,636	6,125	7,441	3.66
329	Mo. No. 7A.....	888	779	765	21.90	.384	.377	12,659	14,461	12,256	14,000	1.31	.9899	58,041	70,439	57,455	1.2136	69,727	5,875	7,130	3.51
330	.....do.........	1,051	889	896	25.92	.438	.441	12,643	14,462	12,236	13,997	1.04	.9920	39,652	48,106	39,335	1.2132	47,721	6,865	8,326	4.10
332	Mo. No. 7B.....	1,299	1,166	1,121	32.03	.574	.552	12,469	14,252	12,278	14,034	.95	.9927	75,968	92,096	75,413	1.2123	91,423	7,735	9,377	4.62
486	Mo. No. 10......	1,001	826	793	24.69	.407	.390	11,653	14,470	11,675	14,498	.29	.9978	53,060	64,367	52,943	1.2131	64,225	5,498	6,669	3.28
470	Mont. No. 2....	1,075	889	845	26.51	.438	.416	11,257	13,768	10,958	13,403	.29	.9978	44,278	53,486	44,176	1.2061	53,369	6,796	8,211	4.04

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds).						Calorific value of fuel per pound (B. t. u.).				Quality of steam (per cent).		Water evaporation.							
		Dry.	Combustible determined from—		Dry per sq. ft. of grate area.	Combustible per sq. ft. of water-heating surface determined from—		By oxygen calorimeter.		By analysis.		Moisture.	Factor of correction (dry steam-unity).	Water fed to boiler (pounds).		Actually corrected for quality of steam (lbs.).	Factor.	Equivalent converted into dry steam from and at 212° F. (lbs.).	Per hour (pounds).		
			Actual w'ght of ash.	Analyses of ash and coal.		Actual weight of ash.	Analysis of ash.	Dry fuel.	Combustible.	Dry fuel.	Combustible.			Total weight.	Equivalent from and at 212° F.				Corrected for quality of steam.	Equivalent from and at 212° F.: Total.	Equivalent from and at 212° F.: Per sq. ft. of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
477	Mont. No. 3	1,094	901	896	26.98	0.444	0.441	11,628	13,682	11,344	13,347	0.48	0.9963	62,151	75,134	61,921	1.2089	74,856	6,903	8,345	4.11
27	N. Mex. No. 1	961	877	830	23.70	.432	.409	12,573	13,947	12,422	13,779	.71	.9946	60,674	71,947	60,346	1.1858	71,558	6,005	7 120	3.51
26	N. Mex. No. 2	1,069	800	803	26.37	.394	.395	11,468	14,071	11,396	13,983	.43	.9967	58,007	68,715	57,815	1.1846	68,488	5,782	6,849	3.37
30	.....do	892	679	672	22.00	.334	.331	12,238	14,890	12,209	14,855	.54	.9958	44,025	52,262	43,840	1.1871	52,042	5,399	6,409	3.16
396	N. Mex. No. 3A	952	792	757	23.48	.390	.373	12,301	14,890	12,335	14,932	1.31	.9899	67,080	79,221	66,402	1.1810	78,421	6,640	7,842	3.86
389	N. Mex. No. 3B	848	721	677	20.91	.355	.333	12,213	14,870	12,130	14,769	1.67	.9871	61,351	72,302	60,560	1.1785	71,370	6,056	7,137	3.51
391	.....do	966	818	780	23.82	.403	.384	12,301	14,881	12,220	14,783	.77	.9941	71,071	83,629	70,652	1.1767	83,136	7,065	8,314	4.09
392	.....do	996	878	850	24.56	.432	.419	13,059	14,986	12,886	14,786	.93	.9928	69,321	81,528	68,822	1.1761	80,941	7,345	8,638	4.25
397	N. Mex. No. 4A	923	796	766	22.76	.392	.377	12,659	14,879	12,735	14,968	.99	.9924	64,172	75,832	63,684	1.1817	75,256	6,368	7,526	3.71
398	.....do	889	792	770	21.92	.390	.379	13,149	14,918	13,198	14,974	.76	.9942	67,278	79,354	66,888	1.1795	78,894	6,642	7,835	3.86
395	N. Mex. No. 4B	865	755	722	21.33	.372	.355	12,847	14,978	12,782	14,903	1.15	.9911	62,829	74,157	62,270	1.1808	73,496	6,178	7,291	3.59
387	N. Mex. No. 5	856	737	702	21.11	.363	.346	12,721	15,148	12,739	15,169	1.51	.9884	62,014	73,170	61,295	1.1799	72,322	6,087	7,182	3.54
33	N. Dak. No. 1	696	616	547	17.15	.303	.269	10,402	12,466	10,192	12,215	1.51	.9881	31,654	37,444	31,278	1.1829	36,999	3,175	3,756	1.85
206	N. Dak. No. 3	1,019	943	880	27.99	.464	.433	11,036	12,555	10,741	12,220	.71	.9945	32,015	37,794	31,839	1.1805	37,586	5,566	6,571	3.24
191	Ohio No. 1	752	634	604	20.66	.312	.297	11,704	14,218	11,698	14,210	.83	.9936	51,360	60,476	51,031	1.1775	60,089	5,144	6,057	2.98
192	.....do	785	702	693	21.57	.346	.341	13,041	14,436	13,043	14,439	.88	.9932	56,191	66,187	55,809	1.1779	65,737	5,542	6,528	3.21
193	Ohio No. 2	750	631	608	20.60	.311	.299	12,190	14,367	12,143	14,311	.71	.9945	49,357	58,177	49,086	1.1787	57,858	4,938	5,815	2.86
197	.....do	749	682	659	18.47	.336	.324	13,113	14,331	13,288	14,522	.40	.9969	51,373	60,548	51,214	1.1786	60,361	5,189	6,116	3.01
203	Ohio No. 3	848	768	760	23.30	.378	.374	13,237	14,493	13,079	14,320	.31	.9976	63,261	74,572	63,109	1.1788	74,393	6,458	7,607	3.75
188	Ohio No. 4	799	713	696	19.70	.351	.343	13,370	14,980	13,327	14,882	.61	.9963	59,496	70,097	59,215	1.1782	69,767	5,846	6,887	3.39
201	.....do	750	669	654	20.60	.329	.322	13,545	15,069	13,500	15,019	.42	.9968	57,327	67,589	57,144	1.1790	67,373	5,726	6,751	3.32

202	.....do.........	792	714	688	21.76	.352	.339	13,374	14,923	13,343	14,888	.35	.9973	57,530	67,822	57,875	1.1789	67,639	6,117	7,211	3.55
219	.....do.........	712	650	640	17.56	.320	.315	13,889	15,052	13,824	14,981	.89	.9932	54,765	65,017	54,393	1.1872	64,575	5,483	6,510	3.21
220	.....do.........	754	693	686	18.60	.341	.338	13,986	15,037	13,945	14,998	.96	.9927	57,178	67,996	56,761	1.1892	67,501	5,676	6,750	3.32
221	.....do.........	742	681	......	18.30	.335	....	13,986	15,038	13,945	14,994	1.67	.9871	35,754	42,604	35,293	1.1916	42,055	5,602	6,675	3.29
186	Ohio No. 5.....	871	801	784	21.49	.394	.386	13,684	14,921	13,495	14,676	1.04	.9920	65,932	77,734	65,405	1.1790	77,112	6,541	7,711	3.80
187	.....do.........	929	860	827	22.91	.423	.407	13,469	14,917	13,246	14,670	.70	.9946	70,212	82,815	69,833	1.1795	82,368	6,983	8,237	4.06
189	.....do.........	790	722	707	19.48	.355	.348	13,532	14,888	13,300	14,640	.62	.9953	62,657	73,804	62,363	1.1779	73,457	6,205	7,309	3.60
190	.....do.........	829	764	734	20.44	.376	.361	13,450	14,908	13,226	14,655	.48	.9963	64,512	75,950	64,273	1.1773	75,669	6,388	7,514	3.70
284	Ohio No. 6.....	651	575	556	17.88	.283	.274	12,974	14,834	13,050	14,921	1.20	.9908	48,828	59,053	48,379	1.2094	58,510	4,872	5,892	2.90
253	.....do.........	638	596	580	15.73	.293	.286	13,901	14,965	13,982	15,052	.75	.9942	39,604	47,477	39,374	1.1988	47,202	4,802	5,756	2.88
268	Ohio No. 7.....	647	577	562	15.96	.284	.277	13,046	14,708	13,127	14,799	1.48	.9886	48,338	58,412	47,787	1.2084	57,746	4,817	5,821	2.87
269	.....do.........	752	677	654	18.55	.333	.322	13,079	14,686	13,158	14,774	1.14	.9912	45,509	54,948	45,109	1.2074	54,465	5,455	6,586	3.24
287	Ohio No. 8.....	775	717	692	21.29	.353	.341	13,136	14,473	13,111	14,446	1.08	.9917	58,365	70,598	57,881	1.2096	70,013	5,770	6,980	3.44
246	Ohio No. 9A...	742	688	671	18.30	.339	.330	13,507	14,747	13,025	14,221	1.09	.9916	45,380	54,438	44,999	1.1996	53,981	5,625	6,748	3.32
249	.....do.........	669	618	597	16.50	.302	.294	13,390	14,766	12,901	14,227	1.12	.9914	48,988	58,810	48,567	1.2005	58,305	4,956	5,949	2.98
250	.....do.........	634	579	567	15.64	.285	.279	13,369	14,758	12,890	14,229	.82	.9937	49,026	58,851	48,717	1.2004	58,480	4,872	5,848	2.88
252	.....do.........	705	657	630	17.39	.323	.310	13,406	14,774	12,929	14,248	.74	.9943	35,355	42,451	35,153	1.2007	42,208	5,302	6,366	3.13
224	Ohio No. 9B...	783	663	638	21.51	.326	.314	12,119	14,454	11,968	14,268	.80	.9939	53,102	63,229	52,778	1.1907	62,843	5,342	6,361	3.18
241	.....do.........	722	674	661	17.81	.332	.325	13,504	14,629	13,253	14,357	.74	.9943	45,515	54,582	45,256	1.1992	54,270	5,601	6,717	3.31
243	.....do.........	739	684	674	18.22	.337	.332	13,374	14,466	13,138	14,211	.69	.9947	53,258	63,888	52,976	1.1996	63,550	5,606	6,725	3.31
244	.....do.........	733	679	672	18.08	.334	.331	13,421	14,467	13,178	14,205	.97	.9925	33,802	40,545	33,548	1.1995	40,241	5,527	6,629	3.26
469	Ohio No. 10....	929	846	831	22.91	.417	.409	13,291	14,636	13,099	14,425	.19	.9985	71,704	86,583	71,596	1.2075	86,452	7,145	8,628	4.25
474	Ohio No. 11....	845	719	732	20.84	.354	.360	13,115	14,746	12,886	14,488	.49	.9963	56,882	68,759	56,672	1.2088	68,505	6,140	7,422	3.65
475	.....do.........	838	728	728	20.67	.358	.358	12,890	14,586	12,658	14,324	.13	.9990	57,097	69,025	57,040	1.2089	68,956	6,147	7,431	3.66
483	Ohio No. 12....	932	827	820	22.98	.407	.404	13,381	14,883	13,167	14,645	.31	.9976	63,725	77,298	63,572	1.2130	77,113	7,025	8,521	4.20
1	Pa. No. 1......	637	609	576	15.70	.300	.284	14,659	15,848	14,474	15,648	1.82	.9858	49,007	57,706	48,311	1.1775	56,886	4,890	5,758	2.84
2	Pa. No. 2......	674	652	622	16.60	.320	.306	14,843	15,802	14,713	15,664	3.16	.9753	57,946	68,185	56,515	1.1767	66,501	5,607	6,597	3.25
36	Pa. No. 3......	771	611	599	19.01	.301	.295	13,289	15,599	13,223	15,522	.62	.9952	53,947	64,494	53,688	1.1955	64,184	5,325	6,366	3.13
74	Pa. No. 4......	757	693	687	18.67	.341	.338	14,400	15,619	14,447	15,671	.38	.9972	59,304	71,811	59,136	1.2109	71,608	5,984	7,246	3.57
207	.....do.........	714	631	625	19.61	.311	.308	13,979	15,518	13,914	15,446	1.25	.9904	59,179	69,908	58,611	1.1813	69,237	5,861	6,924	3.41
208	.....do.........	635	563	550	17.45	.277	.271	13,921	15,532	13,869	15,474	1.27	.9902	53,444	63,112	52,920	1.1809	62,494	5,292	6,249	3.08
209	.....do.........	649	582	568	17.83	.287	.280	13,952	15,526	13,891	15,458	1.37	.9894	53,542	63,313	52,974	1.1825	62,642	5,271	6,233	3.07
286	Pa. No. 5......	671	622	609	18.43	.306	.300	14,029	15,297	14,015	15,282	1.35	.9896	58,035	70,205	57,431	1.2097	69,474	5,743	6,947	3.42
194	.....do.........	747	707	701	20.52	.348	.345	14,526	15,297	14,524	15,295	.70	.9946	61,050	71,984	60,720	1.1791	71,596	6,072	7,160	3.53
195	.....do.........	727	683	677	19.97	.336	.333	14,567	15,314	14,549	15,295	.67	.9949	59,908	70,685	59,602	1.1799	70,324	5,948	7,018	3.46
217	Pa. No. 6......	781	700	668	19.26	.345	.329	13,405	15,303	13,336	15,224	.92	.9929	59,095	70,122	58,675	1.1866	69,624	5,927	7,033	3.46
218	.....do.........	675	600	579	16.65	.295	.285	13,271	15,261	13,212	15,193	.94	.9928	53,485	63,449	53,100	1.1863	62,998	5,337	6,331	3.12
333	.....do.........	875	746	742	21.58	.367	.365	13,163	15,198	13,311	15,369	1.31	.9899	26,385	32,000	26,119	1.2128	31,677	6,324	7,670	3.78
198	Pa. No. 7......	691	596	584	17.04	.293	.288	13,648	15,689	13,583	15,614	.49	.9962	54,187	63,854	53,981	1.1784	63,611	5,382	6,342	3.12
307	.....do.........	663	564	552	16.35	.278	.272	13,455	15,731	13,405	15,673	2.15	.9834	52,006	63,109	51,143	1.2135	62,062	5,079	6,163	3.03
199	.....do.........	679	597	590	16.74	.294	.290	13,828	15,626	13,959	15,774	.46	.9965	54,701	64,585	54,510	1.1807	64,360	5,435	6,417	3.16
236	Pa. No. 8......	573	536	531	15.74	.264	.261	14,886	15,900	14,737	15,741	.84	.9936	49,352	59,114	49,036	1.1978	58,735	4,963	5,945	2.93
237	.....do.........	591	553	545	16.23	.272	.268	14,868	15,898	14,733	15,754	.77	.9941	50,444	60,462	50,146	1.1986	60,105	5,015	6,011	2.96
238	.....do.........	571	538	527	15.69	.265	.259	14,828	15,900	14,688	15,750	.83	.9936	50,062	59,989	49,742	1.1983	59,606	4,964	5,949	2.93
239	.....do.........	642	600	585	17.64	.295	.288	14,690	15,867	14,547	15,711	.69	.9947	52,077	62,466	51,801	1.1995	62,135	5,222	6,264	3.08
242	.....do.........	581	542	532	14.33	.267	.262	14,659	15,745	14,483	15,555	.63	.9952	39,171	46,990	38,983	1.1996	46,764	4,947	5,935	2.92
227	Pa. No. 10.....	694	642	637	19.07	.316	.314	14,341	15,335	14,180	15,163	.92	.9929	59,339	70,780	58,918	1.1928	70,277	5,892	7,028	3.46
228	.....do.........	648	598	592	17.80	.294	.291	14,324	15,331	14,158	15,153	1.48	.9886	55,554	66,248	54,921	1.1925	65,493	5,509	6,569	3.23
229	.....do.........	791	742	731	21.73	.365	.360	14,431	15,360	14,265	15,184	.58	.9955	64,320	77,068	64,031	1.1982	76,722	6,403	7,672	3.78
472	Pa. No. 15.....	684	582	577	16.87	.287	.284	13,729	15,545	13,633	15,436	.51	.9961	44,336	53,607	44,163	1.2091	53,397	5,047	6,103	3.00
473	.....do.........	699	603	609	17.24	.297	.300	14,240	15,766	14,144	15,660	.05	.9996	53,584	64,569	53,563	1.2050	64,543	5,482	6,606	3.25
467	.....do.........	715	632	635	17.63	.311	.313	14,258	15,571	13,954	15,239	.13	.9990	52,695	63,724	52,642	1.2093	63,660	5,935	7,170	3.53
468	Pa. No. 16.....	772	705	694	19.04	.347	.392	14,238	15,614	13,991	15,343	.13	.9990	51,328	62,076	51,277	1.2094	62,014	6,330	7,656	3.77

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds). Dry	Fuel consumed per hour (pounds). Combustible determined from— Actual w'ght of ash.	Fuel consumed per hour (pounds). Combustible determined from— Analyses of ash and coal.	Fuel consumed per hour (pounds). Dry per sq. ft. of grate area.	Fuel consumed per hour (pounds). Combustible per sq. ft. of water-heating surface determined from— Actual weight of ash.	Fuel consumed per hour (pounds). Combustible per sq. ft. of water-heating surface determined from— Analysis of ash.	Calorific value of fuel per pound (B. t. u.). By oxygen calorimeter. Dry fuel.	Calorific value of fuel per pound (B. t. u.). By oxygen calorimeter. Combustible.	Calorific value of fuel per pound (B. t. u.). By analysis. Dry fuel.	Calorific value of fuel per pound (B. t. u.). By analysis. Combustible.	Quality of steam (per cent). Moisture.	Quality of steam (per cent). Factor of correction (dry steam-unity).	Water evaporation. Water fed to boiler (pounds). Total weight.	Water evaporation. Water fed to boiler (pounds). Equivalent from and at 212° F.	Water evaporation. Actually corrected for quality of steam (lbs.).	Water evaporation. Factor.	Water evaporation. Equivalent converted into dry steam from and at 212° F. (lbs.).	Water evaporation. Per hour (pounds). Corrected for quality of steam.	Water evaporation. Per hour (pounds). Equivalent from and at 212° F. Total.	Water evaporation. Per hour (pounds). Equivalent from and at 212° F. Per sq. ft. of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
471	Pa. No. 16.....	751	654	650	18.52	0.322	0.320	13,939	15,372	13,792	15,210	0.22	0.9984	59,602	72,005	59,507	1.2081	71,890	5,933	7,167	3.53
496	Pa. No. 17.....	811	702	685	20.00	.346	.337	13,455	15,474	13,430	15,446	.56	.9957	61,164	74,051	60,901	1.2107	73,733	6,090	7,373	3.63
506	.....do.........	811	715	699	20.00	.352	.344	13,644	15,462	13,617	15,432	.32	.9976	54,032	65,687	53,902	1.2157	65,529	5,840	7,100	3.50
499	Pa. No. 18.....	871	793	775	21.50	.390	.382	14,119	15,709	14,105	15,693	.38	.9971	58,847	71,470	58,676	1.2145	71,262	6,839	8,306	4.09
515	.....do.........	857	783	768	21.13	.386	.378	14,292	15,738	14,054	15,476	.22	.9983	62,016	75,318	61,911	1.2145	75,191	6,715	8,155	4.02
498	Pa. No. 19.....	828	734	738	20.42	.361	.363	14,128	15,372	13,754	14,965	.34	.9974	60,785	73,702	60,627	1.2125	73,510	6,382	7,738	3.81
508	.....do.........	850	773	763	20.96	.381	.376	14,270	15,499	13,799	14,988	.34	.9974	63,684	77,446	63,518	1.2161	77,244	6,772	8,235	4.05
512	Pa. No. 20.....	808	733	725	19.93	.361	.357	14,495	15,951	14,368	15,812	.29	.9978	50,088	60,752	49,978	1.2129	60,618	6,432	7,802	3.84
514	.....do.........	1,116	1,036	1,002	27.52	.510	.493	14,382	15,727	14,200	15,528	.25	.9981	59,493	72,153	59,380	1.2128	72,016	7,488	9,081	4.47
510	Pa. No. 22.....	796	706	688	19.63	.348	.339	13,900	15,569	13,255	14,847	.32	.9976	53,841	65,315	53,712	1.2131	65,158	5,857	7,106	3.50
401	R. I. No. 1....	820	573	525	20.22	.282	.258	11,639	14,001	11,768	14,156	2.76	.9787	28,330	33,225	27,727	1.1728	32,517	3,444	4,039	1.99
344	Tenn. No. 1....	844	746	729	20.81	.367	.359	13,207	14,959	13,063	14,796	1.09	.9916	62,519	75,748	61,994	1.2116	75,112	6,199	7,511	3.70
345	.....do.........	923	790	791	22.76	.389	.389	13,207	14,947	13,077	14,800	1.35	.9896	48,980	59,536	48,471	1.2155	58,917	6,658	8,093	3.98
346	.....do.........	901	799	753	22.22	.393	.371	12,773	14,964	12,641	14,809	1.64	.9874	46,446	56,469	45,861	1.2158	55,758	6,524	7,931	3.90
411	.....do.........	972	925	892	23.97	.455	.439	13,900	15,021	13,714	14,820	1.07	.9918	37,528	44,065	37,220	1.1742	43,704	8,308	9,755	4.80
409	.....do.........	812	762	755	20.02	.375	.372	14,092	15,012	14,159	15,084	1.13	.9913	69,142	81,235	68,540	1.1749	80,528	6,800	7,989	3.93
367	Tenn. No. 2....	1,071	1,018	994	26.41	.501	.489	14,158	15,092	14,033	14,964	.65	.9950	79,492	94,278	79,094	1.1860	93,806	7,933	9,409	4.63
368	.....do.........	777	715	704	19.16	.352	.347	14,008	15,092	13,891	14,966	.85	.9935	62,279	74,442	61,874	1.1953	73,958	6,200	7,411	3.65
369	.....do.........	618	573	564	15.24	.282	.272	14,069	15,092	13,948	14,962	1.66	.9872	50,347	60,190	49,708	1.1955	59,420	4,985	5,960	2.98
349	Tenn. No. 3....	880	836	802	21.70	.412	.395	13,788	14,898	13,765	14,873	1.37	.9894	56,808	68,998	56,201	1.2146	68,202	6,265	7,610	3.75

350	.....do.........	877	820	799	21.63	.407	.393	13,689	14,879	13,666	14,854	.93	.9928	68,487	83,232	67,994	1.2153	82,633	6,799	8,263	4.07
355	Tenn. No. 4....	871	795	772	21.49	.391	.380	13,441	14,904	13,505	15,036	1.28	.9902	68,522	81,055	67,850	1.1829	80,261	6,785	8,026	3.95
356	.....do.........	987	904	865	24.34	.445	.426	13,288	14,969	13,352	15,041	.97	.9925	78,193	91,525	77,607	1.1705	90,839	7,776	9,102	4.48
405	.....do.........	777	713	707	19.16	.351	.348	13,936	15,102	13,772	14,924	1.57	.9879	54,257	63,736	53,600	1.1747	62,964	6,497	7,632	3.76
352	Tenn. No. 5....	766	693	670	18.89	.341	.330	13,004	15,173	13,545	15,107	1.34	.9897	57,811	69,684	56,721	1.2159	68,967	5,683	6,911	3.40
357	.....do.........	911	834	815	22.47	.411	.401	13,792	15,225	13,738	15,165	1.07	.9918	69,024	81,234	68,458	1.1769	80,568	6,846	8,057	3.97
358	.....do.........	897	824	795	22.12	.406	.391	13,685	15,202	13,637	15,149	.93	.9928	72,072	84,281	71,553	1.1694	83,674	7,155	8,367	4.12
379	Tenn. No. 6....	747	641	585	18.42	.316	.288	12,406	15,327	12,416	15,340	.69	.9947	55,404	65,654	55,110	1.1850	65,306	5,578	6,610	3.25
381	.....do.........	744	627	583	18.35	.309	.287	12,505	15,321	12,523	15,343	.33	.9975	49,405	58,752	49,281	1.1892	58,605	4,915	5,849	2.88
372	Tenn. No. 7A..	849	740	721	20.94	.364	.355	12,965	14,969	13,048	15,065	.93	.9928	61,471	73,316	61,028	1.1927	72,788	6,115	7,293	3.59
373	.....do.........	1,085	960	915	26.76	.473	.451	12,681	14,849	12,758	14,933	.57	.9956	76,982	91,840	76,648	1.1930	91,436	7,718	9,208	4.58
374	.....do.........	748	650	632	18.45	.320	.311	12,866	14,967	12,944	15,058	.86	.9934	55,624	66,348	55,257	1.1927	65,904	5,558	6,624	3.26
406	Tenn. No. 7B..	848	785	751	20.91	.387	.370	13,547	15,121	13,772	15,372	.97	.9925	41,353	48,511	41,043	1.1731	48,148	6,674	7,829	3.85
384	Tenn. Nos. 8A and 8B......	634	535	518	15.64	.263	.255	12,758	15,052	12,708	14,993	.17	.9987	44,718	52,919	44,660	1.1834	52,851	4,457	5,275	2.60
385	.....do.........	746	642	630	18.40	.316	.310	13,090	15,157	13,140	15,215	.75	.9943	53,735	63,515	53,429	1.1820	63,153	5,300	6,265	3.08
388	.....do.........	830	749	731	20.47	.369	.360	13,532	15,125	13,797	15,421	.96	.9926	65,835	77,652	65,348	1.1795	77,078	6,515	7,685	3.78
363	Tenn. No. 9A..	803	693	682	19.80	.341	.336	13,257	15,248	13,250	15,240	1.91	.9853	60,528	72,446	59,638	1.1969	71,381	5,964	7,138	3.51
364	.....do.........	888	780	762	21.90	.384	.375	13,333	15,283	13,329	15,279	1.55	.9881	65,966	77,962	65,201	1.1815	77,035	6,553	7,742	3.81
365	.....do.........	852	729	704	21.01	.359	.347	12,938	15,273	12,937	15,272	1.28	.9902	60,973	72,101	60,375	1.1825	71,393	6,050	7,154	3.52
393	Tenn. No. 9B..	876	801	778	21.60	.394	.383	13,613	15,176	13,633	15,198	.78	.9940	71,481	84,197	71,052	1.1779	83,692	7,014	8,262	4.07
407	Tenn. No. 10...	732	623	604	18.05	.307	.297	12,667	14,941	12,722	15,006	1.49	.9885	23,147	27,172	22,881	1.1739	26,860	4,848	5,691	2.80
408	.....do.........	782	654	623	19.28	.322	.307	12,272	14,827	12,521	15,127	1.18	.9909	22,460	26,352	22,256	1.1733	26,113	5,751	6,748	3.32
22	Tex. No. 1.....	421	316	295	10.38	.156	.145	10,886	13,724	10,782	13,593	1.73	.9867	14,807	17,569	14,610	1.1865	17,335	1,666	1,977	.97
291	Tex. No. 4.....	935	822	798	23.06	.405	.393	11,131	12,731	10,696	12,234	1.18	.9909	54,912	66,317	54,412	1.2077	65,718	5,345	6,455	3.18
298	.....do.........	1,282	1,186	1,099	35.22	.584	.541	11,099	12,737	10,665	12,239	.88	.9932	44,811	54,289	44,506	1.2115	53,919	6,225	7,541	3.71
302	.....do.........	1,243	1,067	999	34.15	.525	.492	11,077	12,725	10,647	12,231	.75	.9942	25,008	30,342	24,863	1.2133	30,166	5,755	6,983	3.44
402	Utah No. 2....	1,007	848	806	24.83	.418	.397	12,636	13,512	12,398	13,257	2.12	.9836	31,011	36,419	30,502	1.1744	35,822	4,960	5,825	2.87
403	.....do.........	660	600	569	16.28	.295	.280	12,791	13,689	12,688	13,579	.98	.9925	12,389	14,536	12,296	1.1733	14,427	4,471	5,246	2.58
404	.....do.........	697	599	586	17.19	.295	.289	12,586	13,606	12,307	13,305	2.75	.9787	44,005	51,671	43,068	1.1742	50,570	4,273	5,017	2.47
281	Va. No. 1......	668	625	620	18.35	.308	.305	14,281	15,173	14,083	14,963	1.09	.9916	54,232	65,691	53,776	1.2113	65,139	5,516	6,681	3.29
282	.....do.........	676	638	623	18.57	.314	.307	14,198	15,169	14,006	14,964	1.12	.9914	54,759	66,302	54,288	1.2108	65,732	5,528	6,687	3.29
247	Va. No. 2......	751	715	701	18.52	.352	.345	14,443	15,287	14,211	15,041	1.16	.9911	50,626	60,787	50,175	1.2007	60,245	6,272	7,531	3.71
251	.....do.........	718	681	663	17.71	.335	.326	14,285	15,311	14,049	15,058	.92	.9929	46,480	55,813	46,150	1.2008	55,417	5,769	6,927	3.41
256	.....do.........	664	623	607	18.24	.307	.289	14,317	15,306	14,078	15,050	1.35	.9896	44,831	54,066	44,365	1.2060	53,504	5,263	6,347	3.13
260	.....do.........	656	614	612	18.02	.302	.301	14,497	15,201	14,353	15,050	.75	.9942	52,202	63,055	51,899	1.2079	62,689	5,258	6,351	3.13
280	Va. No. 3......	597	548	555	16.40	.270	.273	14,908	15,651	14,755	15,491	1.36	.9895	48,827	59,051	48,314	1.2094	58,431	4,890	5,914	2.91
283	.....do.........	600	566	560	16.47	.279	.276	14,936	15,666	14,774	15,496	1.29	.9901	50,687	61,306	50,185	1.2095	60,699	5,019	6,070	2.99
240	Va. No. 4......	638	609	594	15.73	.300	.292	14,558	15,306	14,213	14,944	.68	.9948	50,196	60,150	49,935	1.1983	59,837	5,148	6,169	3.04
248	.....do.........	695	......	651	17.14	....	.320	14,677	15,306	14,333	14,947	.93	.9928	47,588	57,115	47,245	1.2002	56,703	5,891	7,070	3.48
254	.....do.........	730	......	688	18.00	....	.339	14,414	14,977	14,384	14,946	1.45	.9888	59,038	70,987	58,377	1.2024	70,193	5,838	7,019	3.46
476	Va. No. 5A....	922	683	671	22.74	.336	.330	12,472	15,493	12,461	15,480	.31	.9976	56,449	68,077	56,314	1.2060	67,915	5,991	7,225	3.56
482	.....do.........	1,432	1,154	1,106	35.31	.568	.545	12,679	15,504	12,661	15,482	.43	.9967	57,767	70,094	57,576	1.2134	69,863	8,817	10,699	5.27
494	Va. No. 5B....	814	667	658	20.07	.328	.324	13,122	15,573	13,097	15,544	.32	.9976	42,118	51,026	42,017	1.2115	50,904	6,002	7,272	3.58
507	Va. No. 6......	835	729	716	20.59	.359	.353	14,177	15,691	13,829	15,306	.35	.9973	54,008	65,577	53,862	1.2142	65,399	6,072	7,373	3.63
290	Wash. No. 1B.	796	657	640	19.63	.323	.315	11,772	13,748	11,614	13,563	1.23	.9905	49,461	59,813	48,991	1.2093	59,245	4,899	5,924	2.92
359	Wash. No. 2...	804	699	687	19.83	.344	.338	12,996	14,880	12,802	14,658	1.07	.9918	59,191	71,148	58,706	1.2020	70,565	5,871	7,057	3.47
360	.....do.........	920	809	797	22.69	.398	.392	13,059	14,882	12,863	14,659	1.49	.9885	66,453	79,850	65,689	1.2016	78,932	6,536	7,854	3.86
361	.....do.........	889	777	771	21.92	.383	.380	13,095	14,886	12,899	14,663	1.10	.9915	65,260	78,279	64,705	1.1995	77,614	6,471	7,761	3.82
412	.....do.........	802	713	704	19.78	.351	.347	13,243	14,940	12,962	14,623	.75	.9943	58,429	68,555	58,096	1.1733	68,164	6,135	7,198	3.54
24	W. Va. No. 1..	768	708	694	18.94	.349	.342	14,198	15,324	14,146	15,268	.58	.9955	58,198	68,936	57,936	1.1845	68,625	5,803	6,878	3.38
25	W. Va. No. 2..	801	722	695	19.75	.355	.342	13,819	15,384	13,489	15,016	.37	.9971	63,406	75,104	63,223	1.1845	74,888	6,187	7,829	3.61

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds).						Calorific value of fuel per pound (B. t. u.).				Quality of steam (per cent).		Water evaporation.							
		Dry.	Combustible determined from—		Dry per sq. ft. of grate area.	Combustible per sq. ft. of water-heating surface determined from—		By oxygen calorimeter.		By analysis.		Moisture.	Factor of correction (dry steam-unity).	Water fed to boiler (pounds).		Actually corrected for quality of steam (lbs.).	Factor.	Equivalent converted into dry steam from and at 212° F. (lbs.).	Per hour (pounds).		
																			Corrected for quality of steam.	Equivalent from and at 212° F.	
			Actual w'ght of ash.	Analyses of ash and coal.		Actual weight of ash.	Analysis of ash.	Dry fuel.	Combustible.	Dry fuel.	Combustible.			Total weight.	Equivalent from and at 212° F.					Total.	Per sq. ft. of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
28	W. Va. No. 3..	804	706	690	19.82	0.348	0.340	13,708	15,454	13,653	15,397	0.52	0.9960	61,612	73,090	61,366	1.1863	72,798	6,155	7,302	3.59
31	W. Va. No. 4..	770	688	668	18.98	.339	.329	14,002	15,601	13,806	15,383	.44	.9966	62,650	74,470	62,437	1.1887	74,219	6,244	7,422	3.65
34	W. Va. No. 5..	748	667	649	18.44	.328	.320	13,854	15,479	13,660	15,263	.58	.9955	60,951	72,605	60,677	1.1912	72,278	6,018	7,168	3.53
39	W. Va. No. 6..	728	677	667	17.95	.333	.328	14,959	15,841	14,800	15,673	.56	.9957	61,384	73,486	61,122	1.1972	73,178	6,143	7,354	3.62
43	.....do.........	698	649	641	17.21	.320	.316	15,033	15,848	14,872	15,678	.76	.9942	61,465	73,660	61,109	1.1984	73,232	6,001	7,192	3.54
51	W. Va. No. 7..	736	675	648	18.15	.332	.319	14,305	15,730	13,770	15,142	.90	.9931	62,010	74,307	61,582	1.1983	73,794	6,048	7,247	3.57
53	W. Va. No. 8..	759	683	686	18.72	.336	.338	14,436	15,564	14,474	15,605	.42	.9968	60,947	73,100	60,752	1.1994	72,866	6,086	7,299	3.59
69	W. Va. No. 9..	727	664	663	17.78	.327	.326	14,616	15,584	14,445	15,401	1.12	.9916	60,651	73,339	60,138	1.2092	72,719	6,014	7,272	3.58
54	W. Va. No. 10.	736	671	663	18.15	.330	.326	15,015	16,025	14,936	15,940	.69	.9947	59,094	70,942	58,781	1.2005	70,567	5,918	7,104	3.50
56	W. Va. No. 11.	735	633	627	18.13	.312	.309	14,180	15,934	13,943	15,668	.72	.9945	61,320	73,890	60,985	1.2050	73,487	6,119	7,374	3.63
46	W. Va. No. 12.	719	661	657	17.68	.326	.324	15,170	15,953	14,990	15,764	.69	.9947	60,466	72,428	60,146	1.1978	72,043	5,936	7,110	3.50
59	.....do.........	716	642	646	17.66	.316	.318	15,235	16,266	15,305	16,341	.59	.9955	62,624	75,249	62,342	1.2016	74,910	6,082	7,308	3.60
179	W. Va. No. 13.	668	641	631	16.47	.316	.311	14,999	15,621	14,978	15,599	1.25	.9904	60,303	70,766	59,724	1.1735	70,086	5,972	7,009	3.45
180	.....do.........	616	590	578	15.19	.290	.285	14,933	15,630	14,918	15,615	.93	.9929	55,830	65,460	55,434	1.1725	64,998	5,571	6,532	3.22
178	W. Va. No. 14.	583	573	564	14.38	.282	.278	15,048	15,403	14,818	15,168	1.28	.9901	52,791	61,956	52,268	1.1736	61,342	5,227	6,134	3.02
181	.....do.........	783	......	741	19.31	....	.365	15,003	15,389	14,778	15,158	1.05	.9919	49,162	57,618	48,764	1.1719	57,151	6,416	7,520	3.70
214	W. Va. No. 15.	594	498	499	16.32	.245	.246	14,128	15,385	14,092	15,348	.89	.9932	40,674	48,191	40,397	1.1848	47,862	4,601	5,451	2.68
215	.....do.........	680	622	609	16.77	.306	.300	14,202	15,413	14,171	15,380	.85	.9935	50,571	59,997	50,242	1.1864	59,607	5,153	6,114	3.01
216	.....do.........	863	799	775	21.28	.393	.382	14,197	15,423	14,166	15,390	.92	.9929	36,707	43,575	36,446	1.1871	43,265	6,284	7,459	3.67
304	W.Va. No. 16A	760	693	677	20.88	.341	.333	13,896	15,160	13,908	15,168	.72	.9945	34,363	41,724	34,174	1.2142	41,494	6,448	7,829	3.85

305	.....do.........	664	614	599	16.37	.302	.295	13,964	15,255	13,891	15,175	.91	.9980	39,946	36,327	29,736	1.2131	36,078	5,570	6,768	3.33
225	W. Va. No. 17.	590	538	538	16.37	.265	.205	14,546	15,711	14,254	15,394	1.11	.9915	51,211	60,941	50,776	1.1900	60,428	5,119	6,091	3.00
226	.....do.........	639	575	575	17.56	.283	.283	14,508	15,722	14,209	15,398	1.00	.9923	53,506	63,779	53,094	1.1920	63,288	5,325	6,348	3.13
230	.....do.........	642	587	585	17.64	.289	.288	14,641	15,650	14,389	15,381	.62	.9953	54,482	65,226	54,226	1.1972	64,918	5,385	6,447	3.17
261	W. Va. No. 18.	648	601	596	17.80	.296	.293	14,414	15,454	14,162	15,184	.77	.9941	56,488	68,356	56,155	1.2101	67,953	5,616	6,795	3.35
262	.....do.........	744	697	684	20.44	.343	.337	14,384	15,452	14,132	15,181	.66	.9949	63,980	77,422	63,654	1.2101	77,028	6,321	7,649	3.77
285	W. Va. No. 19.	566	534	516	15.55	.263	.254	14,618	15,668	14,612	15,661	1.45	.9888	49,386	59,713	48,833	1.2091	59,044	4,898	5,922	2.92
289	.....do.........	562	507	504	13.86	.250	.248	14,571	15,651	14,564	15,643	.64	.9951	38,276	46,360	38,088	1.2112	46,132	4,761	5,727	2.84
331	.....do.........	909	827	836	22.42	.407	.412	14,792	15,782	14,677	15,659	.85	.9935	25,509	30,927	25,343	1.2124	30,726	6,887	8,349	4.11
272	W. Va. No. 20.	562	508	507	15.44	.250	.250	14,202	15,455	14,283	15,544	1.13	.9913	47,026	56,901	46,617	1.2100	56,407	4,699	5,686	2.80
273	.....do.........	603	555	541	16.57	.273	.266	14,083	15,422	14,164	15,510	1.11	.9915	49,816	60,277	49,393	1.2100	59,766	5,004	6,055	2.98
264	.....do.........	627	585	585	17.23	.288	.288	14,584	15,415	14,738	15,578	.94	.9928	54,489	65,866	54,097	1.2088	65,392	5,426	6,559	3.23
266	.....do.........	638	601	595	15.73	.296	.293	14,530	15,410	14,690	15,580	1.33	.9898	52,459	63,475	51,924	1.2100	62,828	5,192	6,283	3.09
274	W. Va. No. 21. .	786	744	745	21.59	.366	.367	14,528	15,265	14,470	15,204	.86	.9984	49,205	59,548	48,880	1.2101	59,150	6,696	8,108	3.99
275	.....do.........	669	621	617	16.50	.306	.304	14,292	15,250	14,231	15,185	2.09	.9839	51,830	62,740	50,996	1.2105	61,731	5,635	6,821	3.36
296	.....do.........	735	683	673	18.13	.336	.331	14,274	15,240	14,213	15,175	1.80	.9861	44,126	53,476	43,513	1.2119	52,733	6,086	7,375	3.63
267	.....do.........	684	650	650	16.87	.320	.320	14,791	15,380	14,609	15,191	1.08	.9917	57,732	69,844	57,253	1.2098	69,265	5,714	6,913	3.40
446	W. Va. No. 22A	768	643	626	18.94	.317	.308	12,838	14,996	12,922	15,094	2.01	.9845	54,610	65,008	53,764	1.1904	64,001	5,261	6,262	3.08
447	.....do.........	820	716	677	20.22	.353	.333	12,843	14,979	12,928	15,078	2.15	.9834	59,333	70,683	58,348	1.1913	69,510	6,028	7,181	3.54
454	.....do.........	851	780	774	20.99	.384	.381	14,152	15,126	14,139	15,112	.26	.9980	66,676	80,058	66,543	1.2007	79,898	6,654	7,990	3.93
438	W. Va. No. 22B	891	819	804	21.97	.408	.396	13,963	15,194	13,734	14,945	1.53	.9882	69,471	82,351	68,651	1.1854	81,379	7,189	8,521	4.20
439	W. Va. No. 23A	810	717	708	19.98	.353	.349	13,995	15,257	13,799	15,043	2.75	.9787	61,675	73,461	60,361	1.1911	71,896	6,066	7,226	3.56
440	.....do.........	763	671	660	18.82	.330	.325	13,781	15,233	13,590	15,021	3.57	.9731	58,738	69,960	57,158	1.1914	68,098	5,815	6,928	3.41
444	W. Va. No. 23B	710	637	643	17.51	.314	.317	14,483	15,245	14,431	15,191	2.44	.9811	54,825	65,308	53,789	1.1912	64,073	5,352	6,375	3.14
445	.....do.........	775	671	652	19.11	.330	.321	13,498	15,141	13,493	15,135	2.05	.9842	59,279	70,619	58,342	1.1913	69,508	5,834	6,950	3.42
63	Wyo. No. 1....	920	940	802	22.69	.413	.395	12,316	13,343	11,947	12,944	.77	.9941	54,675	65,747	54,352	1.2025	65,358	5,355	6,439	3.17
61	Wyo. No. 2....	1,075	769	805	26.51	.379	.396	10,897	13,813	10,552	13,376	.86	.9934	53,068	63,692	52,718	1.2002	63,272	5,298	6,359	3.13
196	Wyo. No. 2B. .	917	677	673	22.61	.333	.331	10,888	14,170	10,559	13,742	.53	.9959	48,389	57,012	48,191	1.1782	56,779	4,878	5,747	2.83
210	.....do.........	934	690	710	25.66	.340	.350	11,261	14,251	10,922	13,822	1.38	.9894	55,193	65,161	54,608	1.1806	64,470	5,417	6,396	3.15
213	.....do.........	1,186	905	872	32.58	.446	.429	10,751	14,066	10,424	13,639	.84	.9936	61,633	73,035	61,239	1.1850	72,568	6,106	7,235	3.56
211	Wyo. No. 3....	690	574	530	18.96	.283	.261	10,519	13,096	10,305	12,829	1.59	.9877	41,836	49,412	41,321	1.1811	48,804	4,112	4,856	2.39
212	.....do.........	949	797	743	26.07	.392	.366	10,517	12,945	10,303	12,682	1.00	.9923	53,340	63,091	52,929	1.1828	62,604	5,401	6,388	3.15
223	.....do.........	728	651	648	20.00	.321	.319	12,641	13,798	12,116	13,225	.96	.9926	44,556	52,946	44,226	1.1883	52,554	4,941	5,872	2.89
399	Wyo. No. 4....	972	856	843	23.97	.421	.415	12,222	13,246	12,605	13,661	.93	.9928	59,133	69,617	58,707	1.1773	69,116	5,859	6,898	3.40
400	Wyo. No. 6....	990	881	852	24.41	.434	.419	12,488	13,222	12,524	13,260	.85	.9935	57,901	68,057	57,525	1.1754	67,615	5,741	6,748	3.32
419	.....do.........	570	486	478	14.06	.239	.235	13,021	13,471	12,782	13,224	.75	.9943	32,775	38,330	32,588	1.1695	38,112	3,448	4,033	1.99
	MISCELLANEOUS.																				
451	Arg. Rep. No 1.	986	507	365	24.32	.250	.180	5,983	12,873	5,918	12,840	.25	.9981	16,928	20,235	16,891	1.1967	20,197	2,073	2,478	1.22
458	.....do.........	875	549	482	21.58	.270	.237	8,298	13,279	8,037	12,861	.13	.9990	28,267	34,059	28,239	1.2049	34,025	3,180	3,832	1.89
485	.....do.........	1,271	746	633	31.34	.367	.312	8,235	13,614	8,458	13,982	.26	.9980	12,482	15,114	12,457	1.2109	15,084	4,449	5,387	2.65
172	Brazil No. 1...	917	704	630	22.61	.347	.310	10,028	13,839	10,044	13,861	2.26	.9825	24,667	28,947	24,235	1.1735	28,440	4,530	5,816	2.62
173	.....do.........	1,011	759	689	24.93	.374	.339	9,830	13,622	9,847	13,646	1.24	.9905	29,685	34,806	29,403	1.1725	34,475	5,251	6,156	3.03
	Mixed coals accurately sized:																				
348	1½ to 3 inches.	966	827	832	23.82	.407	.410	12,577	14,263	12,407	14,070	1.05	.9919	57,731	70,218	57,263	1.2163	69,649	5,908	7,180	3.54
347	1 to 1½ inches.	954	810	800	23.53	.399	.394	12,292	14,315	11,966	13,935	.94	.9928	32,977	40,110	32,740	1.2163	39,822	5,795	7,048	3.47
351	¾ to 1 inch....	786	671	660	19.38	.330	.325	12,168	14,213	12,109	14,144	2.63	.9797	35,309	42,971	34,592	1.2170	42,098	4,907	5,971	2.94
362	½ to ¾ inch...	820	730	682	20.22	.359	.366	11,819	13,964	11,635	13,746	2.08	.9839	28,493	34,175	28,034	1.1994	33,625	5,270	6,320	3.11
366	⅜ to ½ inch....	954	825	791	23.53	.406	.389	12,053	14,224	11,885	14,025	.99	.9924	25,511	29,590	25,317	1.1599	29,365	5,860	6,797	3.35

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Fuel consumed per hour (pounds).						Calorific value of fuel per pound (B. t. u.).				Quality of steam (per cent).		Water evaporation.							
		Dry.	Combustible determined from—		Dry per sq. ft. of grate area.	Combustible per sq. ft. of water-heating surface determined from—		By oxygen calorimeter.		By analysis.		Moisture.	Factor of correction (dry steam-unity).	Water fed to boiler (pounds).		Actually corrected for quality of steam (lbs.).	Factor.	Equivalent converted into dry steam from and at 212° F. (lbs.).	Per hour (pounds).		
			Actual w'ght of ash.	Analyses of ash and coal.		Actual weight of ash.	Analysis of ash.	Dry fuel.	Combustible.	Dry fuel.	Combustible.			Total weight.	Equivalent from and at 212° F.				Corrected for quality of steam.	Equivalent from and at 212° F. Total.	Equivalent from and at 212° F. Per sq. ft of water-heating surface.
1	2	52 (46)	53 (47)	54 (47.1)	55 (48)	56 (49)	57 (49.1)	58 (50)	59 (51)	60 (52)	61 (53)	62 (54)	63 (56)	64 (57)	65 (58)	66 (59)	67 (60)	68 (61)	69 (62)	70 (63)	71 (64)
	MISCELLANEOUS—Con. Mixed coals accurately sized—Con.																				
370	¼ to ⅜ inch....	914	754	739	22.54	0.371	0.364	11,623	14,044	11,590	14,004	1.72	0.9867	18,883	22,563	18,632	1.1949	22,263	5,369	6,416	3.16
371	Under ¼ inch.	742	590	548	18.29	.290	.270	10,991	13,923	10,721	13,581	2.32	.9821	20,540	24,527	20,172	1.1941	24,088	3,917	4,677	2.30
	Mixed coals:																				
245	Pa. No. 8 dried and Va. No. 4..	695	649	632	17.14	.320	.311	14,476	15,354	14,108	14,964	.86	.9934	40,702	48,842	40,433	1.2000	48,520	5,171	6,205	3.06
414	Utah No. 1 and R. I. No. 1......	747	655	643	18.42	.323	.317	12,845	14,434	12,800	14,384	1.08	.9917	25,847	30,316	25,632	1.1729	30,064	5,126	6,018	2.96
415	.....do.........	771	676	667	19.01	.333	.328	12,823	14,324	12,664	14,147	.63	.9952	28,305	33,137	28,169	1.1707	32,977	5,634	6,595	3.25
416	Utah No. 2 and R. I. No. 1......	1,075	785	734	26.51	.387	.361	12,244	13,600	12,274	13,633	1.05	.9919	48,669	57,064	48,275	1.1725	56,602	4,818	5,649	2.78

	Special tests:																				
500	Illinois......	1,018	897	893	25.10	.442	.440	12,586	14,053	12,717	14,199	.10	.9992	60,357	73,358	60,309	1.2154	73,300	6,686	8,126	4.00
501	.....do..........	899	790	788	22.17	.389	.388	12,828	14,294	12,753	14,216	.08	.9994	35,481	43,131	35,460	1.2156	43,105	5,528	6,714	3.31
502	.....do..........	887	776	771	21.87	.382	.380	12,649	14,257	12,577	14,176	.06	.9996	50,016	60,749	49,996	1.2146	60,725	5,668	6,885	3.39
503	.....do..........	993	855	842	24.49	.421	.415	12,434	14,248	12,380	14,186	.45	.9966	46,319	56,370	46,162	1.2170	56,179	6,350	7,728	3.81
504	.....do..........	980	865	863	24.17	.426	.425	12,739	14,281	12,661	14,194	.46	.9965	38,405	46,658	38,271	1.2149	46,495	6,008	7,299	3.59
505	.....do..........	1,231	1,075	1,071	30.36	.529	.527	12,670	14,276	12,600	14,197	.59	.9955	57,989	70,567	57,728	1.2169	70,249	7,833	9,532	4.69
517	.....do..........	584	465	498	28.77	.229	.245	12,861	14,341	12,787	14,258	.18	.9986	24,459	29,681	24,425	1.2135	29,640	3,859	4,682	2.31
479	Wash'ry refuse	1,478	708	653	36.45	.349	.322	7,241	13,637	7,103	13,377	.42	.9968	31,319	37,890	31,219	1.2098	37,768	4,348	5,260	2.59
519	Mixed coke....	1,132	989	944	27.92	.487	.465	12,366	14,339	12,040	13,961	.00	1.0000	69,533	84,239	69,533	1.2115	84,239	7,795	9,444	4.65

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Horsepower: Developed on test.	Horsepower: Builder's rating.	Horsepower: Per cent of rated horsepower developed.	Economic results (pounds of water evaporated per pound of fuel): Apparent under actual conditions as fired.	Equivalent from and at 212° F.: As fired.	Equivalent from and at 212° F.: Dry.	Combustible determined from—Actual weight of ash.	Combustible determined from—Analysis of ash and coal.	Efficiency (per cent) of—Boiler, from actual weight of ash.	Efficiency (per cent) of—Boiler, from analysis of ash and coal.	Efficiency (per cent) of—Boiler and grate.	Smoke (per cent of black).	Kind of firing.	Methods of firing: Thickness of fire (inches)	Interval between: Normal firings (minutes).	Interval between: Times of leveling or breaking up (hours).
1	2	72(65)	73(66)	74(67)	75(68)	76(69)	77(70)	78(71)	79(71.1)	80(72)	81(72.1)	82(73)	83(77)	84(80)	85(81)	86(82)	87(83)
17	Alabama No. 1	205.7	210	97.9	7.02	8.22	8.44	10.08	10.36	64.49	66.28	63.01	40.0	Alternate	8	6.0	1.0
21	....do	196.6	210	93.6	7.29	8.58	8.81	10.17	10.52	64.64	66.86	64.93	20.0	....do	10	5.0	....
16	Alabama No. 2	216.4	210	103.0	6.92	8.13	8.55	9.91	10.22	65.38	67.42	65.68	54.0	....do	8	5.7	2.0
382	Alabama No. 2B	228.0	210	108.6	6.68	7.93	8.24	9.56	9.80	63.84	65.44	64.12	30.0	....do	....	3.4	1.1
383	....do	166.3	210	79.2	6.64	7.88	8.20	9.71	9.92	64.82	66.22	64.54	....	....do	6	5.1	1.4
410	....do	191.9	210	91.4	7.50	8.69	9.00	10.24	10.63	66.98	69.52	67.60	.0	....do	6	4.3	2.0
390	Alabama No. 3	194.7	210	92.7	6.69	7.77	8.00	9.70	10.49	62.35	67.43	65.44	.0	....do	8	3.6	1.4
394	....do	199.0	210	94.8	6.70	7.82	8.05	9.53	10.21	61.25	65.62	63.85	16.5	....do	8	3.5	1.4
375	Alabama No. 4	224.4	210	106.9	7.37	8.75	9.12	10.21	10.55	64.25	66.38	64.42	11.5	....do	8	3.6	1.3
376	....do	174.8	210	83.2	6.88	8.14	8.55	9.94	10.46	62.55	65.82	63.31	6.5	....do	6	4.3	.9
377	....do	182.7	210	87.0	6.73	7.95	8.43	9.90	10.81	62.24	67.96	65.40	17.0	....do	5	4.0	.6
378	....do	162.5	210	77.4	7.04	8.24	8.69	10.09	10.46	63.29	65.61	63.36	.0	....do	7	4.2	.6
413	....do	229.5	210	109.5	7.75	9.02	9.25	10.14	10.29	64.00	64.95	64.12	5.0	....do	7	4.5	3.3
478	Alabama No. 5	173.4	210	82.6	6.08	7.33	7.76	9.90	10.34	63.25	66.06	62.80	4.5	Alternate, spreading.	6	3.5	.4
480	....do	219.6	210	104.6	6.40	7.70	8.17	10.06	10.65	63.97	67.72	63.96	4.0	Alternate	7	3.1	.7
484	Alabama No. 6	235.7	210	112.2	7.96	9.64	9.92	10.92	10.99	67.45	67.88	66.30	14.0	....do	5	3.7	.7
9	Arkansas No. 1	180.5	210	86.0	7.59	8.86	9.05	10.36	10.72	63.90	66.13	64.39	2.5	....do	5	6.0	1.0
14	....do	206.4	210	98.3	7.90	9.28	9.37	10.57	10.76	66.17	67.33	65.39	18.6	....do	12	5.0	1.5
8	Arkansas No. 2	180.5	210	86.0	8.29	9.63	9.73	10.65	10.97	66.05	68.04	65.96	5.1	....do	8	6.0	1.3
11	....do	190.3	210	90.3	7.51	8.86	9.31	10.75	10.88	66.66	67.47	66.32	5.5	....do	10	5.5	....
29	Arkansas No. 3	219.7	210	104.6	7.87	9.31	9.50	10.88	11.15	67.24	68.91	64.83	9.6	....do	10	5.2	.5
35	....do	200.8	210	95.6	6.84	8.12	8.34	10.14	10.56	62.91	65.51	63.48	2.6	....do	9	5.8	.3
40	Arkansas No. 4	214.5	210	102.1	7.59	9.04	9.40	11.06	11.39	68.49	70.53	65.05	4.6	Spreading	12	10.0	.6
42	....do	166.8	210	79.4	6.50	7.73	7.98	10.61	10.98	64.41	66.65	55.42	3.2	....do	8	9.6	.5

41	Arkansas No. 5	202.4	210	96.4	6.60	7.86	8.04	10.34	10.20	64.70	63.82	57.02	2.0	do	6	7.7	.7
293	Arkansas No. 7A	152.9	210	72.8	7.55	8.97	9.48	11.15	11.02	70.14	69.32	66.80	.0	Alternate	12	5.5	.4
294	do	180.0	210	85.7	7.01	8.35	8.84	10.00	10.34	62.93	65.07	63.09	.0	do	10	6.5	.5
297	Arkansas No. 8	178.5	210	85.0	6.69	7.93	8.19	10.20	10.49	64.08	65.90	60.84	.0	Spreading	5	7.9	1.6
308	do	169.9	210	80.9	7.01	8.42	8.96	10.99	10.82	68.70	67.64	61.26	.0	do	6	7.7	1.8
309	do	223.2	210	106.3	6.69	8.08	8.59	9.62	10.06	60.16	62.92	58.61	.0	do	10	6.4	2.5
340	Arkansas No. 10	218.4	210	104.0	2.99	3.59	5.86	6.78	7.60	53.76	60.25	59.26	.0	do	8	4.9	1.1
75	Colorado No. 1	151.0	210	71.9	4.81	5.78	7.21	8.41	8.55	60.19	61.26	55.36	5.8	do	6	7.2	1.1
386	Florida No. 1	237.7	210	113.2	4.27	5.00	6.04	6.37	6.63	55.91	58.19	57.85	13.0	do	7	3.7	1.0
481	Georgia No. 1	234.8	210	111.8	7.20	8.67	8.95	11.12	11.39	68.64	70.81	67.18	2.5	Alternate	8	3.3	1.1
18	Illinois No. 1	211.4	210	100.7	5.54	6.51	7.21	8.76	9.02	59.36	61.12	58.73	37.0	do	7	4.8	1.0
19	Illinois No. 2	210.2	210	100.1	6.09	7.16	8.00	8.92	9.22	60.83	62.88	61.47	26.6	do	6	4.7	.7
38	Illinois No. 3	200.6	210	95.5	6.19	7.35	8.04	9.53	9.78	62.42	64.20	60.39	11.4	do	7	5.2	.6
48	Illinois No. 4	172.0	210	81.9	5.39	6.38	7.37	8.61	8.74	58.05	58.93	57.27	9.2	do	9		.6
50	do	197.8	210	94.2	5.34	6.36	7.27	8.44	8.63	56.92	58.20	56.35		Spreading	7	7.0	.8
73	Illinois No. 6	194.3	210	92.5	5.32	6.43	7.40	8.75	9.20	60.39	63.50	61.64		do	7	6.9	1.4
106	Illinois No. 6B	200.1	210	95.3	4.69	5.56	6.56	7.36	7.45	49.95	50.56	49.64		Alternate	8	3.8	.5
313	do	165.2	210	78.7	5.85	7.03	8.16	9.39	9.69	65.07	67.15	65.51	.0	do	8	5.3	1.4
314	do	201.3	210	95.9	4.98	5.99	6.91	7.98	8.21	54.02	55.98	55.14		do	8	4.5	1.4
122	Illinois No. 7C	128.9	210	61.4	4.71	5.44	6.08	8.46	8.97	58.59	62.12	58.71		do	5	4.6	.3
129	do	188.1	210	89.6	5.75	6.70	8.02	9.08	9.17	61.51	62.12	60.84		do	6	4.1	.6
142	Illinois No. 7D	175.0	210	83.3	5.73	6.65	7.42	8.85	9.25	59.97	62.68	61.39		do	5	4.8	.9
143	do	158.6	210	75.5	5.59	6.46	7.20	8.63	9.27	59.07	63.45	62.01		do	5	4.7	.8
146	do	157.9	210	75.2	5.68	6.64	7.40	9.12	9.80	62.48	67.09	64.45	11.0	do	8	4.7	.7
516	Illinois No. 7E	217.7	210	103.7	4.09	4.95	5.79	7.94	8.21	55.19	57.06	54.38	38.5	do	2	3.6	.9
101	Illinois No. 8	189.2	210	90.1	4.56	5.39	6.22	7.42	7.75	50.77	53.03	49.86		Spreading	8	5.7	.3
102	do	213.2	210	101.5	4.71	5.58	6.39	7.41	7.70	50.68	52.66	51.41		Alternate	8	4.2	.5
103	Illinois No. 9A	212.3	210	101.1	5.06	5.94	6.81	7.74	7.87	52.69	53.57	52.59		do	8	4.2	1.7
104	do	177.3	210	84.4	4.85	5.70	6.50	7.44	7.63	50.25	51.54	50.28		do	9	4.7	.7
105	do	240.0	210	114.3	4.99	5.93	6.75	7.52	7.79	50.86	52.68	51.92		Spreading	8	5.0	1.7
113	do	179.8	210	85.6	4.84	5.68	6.66	7.40	7.50	50.38	51.06	49.67		Alternate	6	4.1	.6
121	Illinois No. 9B	210.0	210	100.0	5.72	6.69	7.49	8.59	8.83	58.00	59.62	58.15		do	5	3.8	.6
492	Illinois No. 9C	206.2	210	98.2	5.51	6.65	7.79	9.17	9.37	61.62	62.97	62.50	4.3	do	6	5.0	.6
107	Illinois No. 10	188.8	210	89.9	5.73	6.76	7.65	8.91	9.17	59.16	60.88	59.44		do	10	4.3	.4
108	do	184.1	210	87.6	5.41	6.39	7.04	8.10	8.28	53.76	54.95	53.60		do	10	4.7	.5
109	do	174.3	210	83.0	5.83	6.90	7.70	9.17	9.52	60.88	63.20	60.10		do	10	4.3	.3
110	do	146.2	210	69.6	5.16	6.08	6.71	8.02	8.05	53.26	53.46	50.12		do	10-14	4.9	.3
114	do	207.3	210	98.7	6.07	7.16	8.11	8.89	8.94	59.02	59.35	57.82		do	7	4.1	.6
137	Illinois No. 11A	186.4	210	88.8	6.65	7.76	8.42	9.80	10.19	66.21	68.84	64.51		do	6	4.7	1.0
138	do	175.1	210	83.4	6.59	7.68	8.32	9.72	10.13	65.55	68.31	66.08		do	6	4.7	1.0
139	do	180.3	210	85.9	6.86	8.02	8.67	10.12	10.42	68.49	70.52	68.33		do	5	5.1	1.2
141	do	183.4	210	87.3	6.58	7.66	8.29	9.30	9.70	62.65	65.34	64.02		do	5	4.8	1.0
111	Illinois No. 11B	172.2	210	82.0	5.23	6.15	6.70	8.00	8.21	53.06	54.46	51.18		do	8	4.7	.4
112	do	170.6	210	81.2	5.59	6.59	7.23	8.88	8.99	58.19	58.91	54.65		do	8	4.5	.7
115	do	201.5	210	95.9	5.82	6.83	7.49	8.79	9.20	57.60	60.28	58.71		do	8	4.1	.5
116	do	212.8	210	101.3	5.86	6.94	7.48	8.63	8.79	56.59	57.64	55.85		do	8	4.4	.5
117	do	201.1	210	95.8	5.73	6.71	7.19	8.32	8.51	55.32	56.58	55.38		do	8	4.1	.6
118	do	195.5	210	93.1	5.76	6.74	7.19	8.32	8.46	54.94	55.87	54.26		do	6	4.2	.6
119	do	220.6	210	105.0	5.81	6.84	7.31	8.29	8.46	54.17	55.28	53.97		do	8	3.9	.7
120	Illinois No. 11C	209.0	210	99.5	6.03	7.08	7.79	8.71	8.74	57.72	57.92	56.27		do	6	3.9	.5
312	do	200.4	210	95.4	6.64	7.96	8.80	9.84	9.83	64.88	64.81	63.60	.0	do	9	4.9	1.8
127	Illinois No. 12	197.4	210	94.0	6.17	7.15	7.81	9.24	9.60	62.18	64.61	63.04		do	7	4.2	1.3

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Horsepower.			Economic results (pounds of water evaporated per pound of fuel).					Efficiency (per cent) of—			Smoke (per cent of black).	Kind of firing.	Methods of firing.		
						Equivalent from and at 212° F.										Interval between.	
								Combustible determined from—									
		Developed on test.	Builder's rating.	Per cent of rated horsepower developed.	Apparent under actual conditions as fired.	As fired.	Dry.	Actual weight of ash.	Analysis of ash and coal.	Boiler, from actual weight of ash.	Boiler, from analysis of ash and coal.	Boiler and grate.			Thickness of fire (inches)	Normal firings (minutes).	Times of leveling or breaking up (hours).
1	2	72(65)	73(66)	74(67)	75(68)	76(69)	77(70)	78(71)	79(71.1)	80(72)	81(72.1)	82(73)	83(77)	84(80)	85(81)	86(82)	87(83)
128	Illinois No. 12	206.5	210	98.3	6.45	7.54	8.19	9.46	9.84	63.71	66.26	65.07		Alternate	7	3.9	1.3
131	do	171.2	210	81.5	6.06	7.04	7.77	9.63	10.19	64.52	68.28	64.08		do	7	4.4	.8
133	do	185.2	210	88.2	5.99	7.00	7.67	9.32	9.73	62.96	65.73	62.51		do	7	4.4	.9
135	do	213.0	210	101.3	6.69	7.86	8.75	9.93	9.90	65.65	66.05	64.48		do	6	4.5	1.4
136	do	171.2	210	81.5	6.00	7.00	7.81	9.60	9.88	64.55	66.43	63.56		do	6	4.7	.9
463	Illinois No. 12B	188.4	210	89.7	6.61	7.98	8.58	9.81	9.84	65.43	65.63	64.44	5.0	do	5	3.6	1.7
132	Illinois No. 13	198.4	210	94.5	6.57	7.67	8.52	10.00	10.16	66.72	67.79	65.67		do	6	4.6	1.2
134	do	199.6	210	95.0	6.48	7.58	8.39	9.73	9.83	65.11	65.78	63.96		do	7	4.5	1.1
144	do	218.0	210	103.8	7.05	8.20	9.08	10.17	10.09	67.86	67.33	66.12	36.0	do	8	4.4	1.8
145	do	198.9	210	94.7	7.16	8.37	9.36	10.23	10.36	68.28	69.15	67.93	28.0	do	8	4.9	1.3
123	Illinois No. 14	182.6	210	86.9	5.57	6.49	7.34	8.63	8.90	58.76	61.21	59.03		do	5	4.1	.7
125	do	181.1	210	86.2	5.70	6.62	7.58	8.84	9.05	60.35	61.78	60.37		do	5	4.6	1.0
130	do	196.0	210	93.3	5.57	6.49	7.71	8.75	8.86	59.04	59.79	58.48		do	6	4.2	1.2
126	Illinois No. 15	183.2	210	87.2	5.94	6.86	7.62	9.11	9.49	62.06	64.68	62.63		do	7	4.6	.8
152	do	198.1	210	94.3	6.51	7.57	8.59	9.69	9.64	64.60	64.26	63.30		do	6	4.2	1.1
150	Illinois No. 16	209.5	210	99.8	7.11	8.24	9.08	10.16	10.42	67.63	69.36	68.11	35.0	do	8	4.2	1.9
140	Illinois No. 18	168.3	210	80.1	6.51	7.60	8.61	9.79	9.90	65.33	66.06	64.20		do	5	5.3	1.4
148	do	176.1	210	83.9	6.13	7.06	7.94	8.98	9.13	59.51	60.50	59.02		do	8	4.4	1.3
147	do	183.5	210	87.4	6.49	7.57	8.91	9.94	9.86	66.01	65.48	63.48		do	6	4.6	1.4
149	do	193.6	210	92.2	6.61	7.70	9.23	10.44	10.08	69.84	67.50	66.36	18.4	do	8	4.4	.8
160	Illinois No. 19A	180.9	210	86.1	6.27	7.27	8.33	9.28	9.45	62.25	63.40	61.71	28.3	do	8	4.3	.7
161	do	183.9	210	87.6	6.54	7.62	8.80	10.06	10.17	67.54	68.27	65.82	13.0	do	8	4.2	.6
163	do	210.5	210	100.2	6.45	7.50	8.61	9.57	9.70	64.19	65.06	63.66	7.0	do	8	4.3	.5
170	do	182.6	210	87.0	6.37	7.42	8.56	9.76	9.85	65.49	66.09	64.29	6.4	do	7	4.5	1.3
171	do	190.2	210	90.6	6.71	7.79	8.97	10.20	10.30	68.42	69.09	67.06	13.0	do	8	4.4	1.1

175	Illinois 19B	219.9	210	104.7	6.96	8.13	9.10	10.47	10.53	68.86	69.26	67.50	32.0	do	8	4.1	2.5
204	do	206.2	210	98.2	7.27	8.54	9.45	10.42	10.83	68.64	71.34	69.93	31.4	do	6	4.5	2.5
206	do	199.2	210	94.9	7.11	8.32	9.27	10.42	10.83	68.57	71.27	68.86	28.8	do	7	4.4	2.0
420	Illinois No. 19C	197.1	210	93.9	6.61	7.67	8.40	9.59	10.00	64.47	67.28	65.26	.0	do	6	3.4	1.4
428	do	170.0	210	81.0	6.66	7.73	8.53	9.84	10.12	66.12	68.01	65.92	.0	do	9	3.8	.9
424	Illinois No. 19D	187.2	210	89.1	6.73	7.81	8.53	9.75	10.00	66.17	67.87	66.35	.0	do	5	3.5	1.3
425	do	195.4	210	93.0	6.79	7.87	8.61	9.82	10.09	66.65	68.48	66.73	5.5	Spreading	7	3.6	1.7
421	Illinois No. 19E	194.0	210	92.5	6.63	7.70	8.48	9.67	9.98	65.69	67.46	65.76	8.5	Alternate	5	4.0	1.3
423	do	199.5	210	95.0	6.78	7.88	8.73	9.89	10.20	66.57	68.66	67.08	8.0	do	6	3.2	.8
292	Illinois No. 20	139.3	210	66.3	5.47	6.55	7.66	9.51	9.61	65.82	66.51	64.75	.0	do	6	5.2	.7
301	do	208.5	210	99.3	5.57	6.71	8.04	9.00	9.43	60.80	63.71	62.08	32.5	do	6	3.2	1.7
302	do	224.1	210	106.7	5.74	6.91	8.27	9.17	9.57	61.91	64.61	63.65	27.2	do	5	3.3	2.3
315	Illinois No. 21	192.4	210	91.6	5.76	6.94	8.16	9.31	9.95	63.09	67.42	65.97	......	do	5	3.8	1.2
316	do	187.6	210	89.3	5.67	6.76	7.96	9.11	9.53	61.51	64.35	62.80	.0	do	7	3.6	1.3
318	do	242.2	210	115.3	5.60	6.73	8.14	9.31	9.40	63.38	64.00	63.04	.0	Spreading	6	5.1	2.4
324	Illinois No. 22A	211.8	210	100.9	5.78	6.91	7.81	9.10	9.70	62.87	67.01	65.67	68.3	Alternate	12	4.0	1.4
326	do	212.0	210	101.0	5.92	7.14	7.97	9.19	9.61	63.20	66.09	64.81	25.6	do	10	3.9	1.7
328	do	255.7	210	121.8	5.78	6.97	8.14	9.14	9.16	61.74	61.88	60.82	27.0	do	6	3.4	2.0
306	do	177.1	210	84.3	5.80	6.97	8.15	9.40	9.87	65.05	68.31	66.98	15.5	do	7	3.9	1.7
317	do	189.9	210	90.4	5.89	7.02	8.23	9.17	9.31	62.02	62.97	62.12	.0	do	6	3.7	1.4
321	Illinois No. 23B	222.5	210	106.0	5.72	6.89	7.97	8.83	8.92	59.23	59.83	59.22	22.0	do	12	3.8	.6
322	do	223.9	210	106.6	5.62	6.71	7.76	8.60	8.68	57.69	58.22	57.66	17.0	Spreading	14	6.3	.7
335	Illinois No. 24B	194.5	210	92.6	5.90	7.09	8.07	9.27	9.50	63.40	64.97	63.64	7.0	Alternate	8	4.2	1.4
336	do	193.8	210	92.3	5.59	6.71	7.67	9.10	8.97	61.76	60.87	58.68	......	do	8	4.1	1.2
337	do	224.8	210	107.0	5.84	7.00	8.10	9.72	9.43	66.14	64.17	62.71	......	do	10	3.6	1.9
338	Illinois Nos. 25A and 25B	182.7	210	87.0	5.35	6.38	7.28	8.75	8.68	58.52	58.05	56.16	.0	do	6	4.4	2.4
339	do	208.1	210	99.1	5.55	6.63	7.50	8.92	9.19	60.48	62.32	60.25	.0	do	6	3.8	2.5
341	Illinois No. 26	167.4	210	79.7	5.52	6.56	7.58	9.10	9.29	61.99	63.28	60.85	28.0	do	5	4.7	1.7
342	do	186.1	210	88.6	5.40	6.47	7.67	9.31	9.29	62.82	62.68	60.42	6.0	do	9	3.8	1.5
353	Illinois No. 27	184.7	210	88.0	5.57	6.66	7.93	9.18	9.65	62.65	65.86	64.73	16.0	do	7	4.2	2.0
354	do	181.4	210	86.4	5.60	6.75	8.02	9.42	9.85	64.80	67.75	66.12	8.5	do	6	4.1	1.4
459	Illinois No. 28A	184.1	210	87.7	6.43	7.75	8.36	9.62	9.79	64.30	65.44	64.29	.0	do	6	4.5	.8
457	Illinois No. 28B	201.4	210	95.9	6.78	8.13	8.64	9.92	10.11	65.97	67.23	64.99	4.0	do	6	4.4	.9
448	Illinois No. 28C	228.4	210	108.8	7.01	8.21	8.63	9.79	9.99	65.06	66.38	64.50	17.0	do	9	3.6	1.4
452	do	232.1	210	110.5	6.97	8.35	8.98	10.20	10.36	67.63	68.70	66.35	12.0	do	4	3.7	.9
465	Illinois No. 29A	213.2	210	101.5	6.34	7.65	8.91	9.94	9.89	67.04	66.71	65.58	6.0	do	7	3.5	2.0
460	Illinois No. 29B	202.3	210	96.3	5.93	7.16	8.05	9.46	9.88	64.39	67.25	65.08	7.0	do	5	3.4	1.0
461	do	218.8	210	104.2	6.05	7.31	8.34	9.27	9.58	62.29	64.37	63.28	7.0	do	6	3.0	1.4
466	do	229.4	210	109.2	6.52	7.87	8.74	9.88	10.03	65.91	66.91	66.14	13.0	do	6	3.2	1.7
511	Illinois No. 30	211.5	210	100.7	6.41	7.76	8.60	9.45	9.59	62.43	63.36	62.58	.0	do	10	4.1	.9
489	Illinois No. 31	205.2	210	97.7	5.84	7.06	8.25	9.67	9.81	64.94	65.89	64.76	2.0	do	9	4.1	.7
491	do	209.9	210	100.0	6.09	7.35	8.24	9.74	9.77	65.37	65.58	64.51	2.5	do	4	3.3	1.9
513	Illinois No. 33	190.4	210	90.7	4.49	5.43	6.13	8.31	8.53	55.40	56.86	53.34	2.0	do	10	4.6	.6
509	Illinois No. 34B	223.0	210	106.2	6.80	8.24	8.82	9.84	9.79	64.00	63.68	62.53	13.0	do	9	3.9	1.1
71	Indiana No. 1	222.6	210	106.0	6.40	7.70	8.73	9.45	9.47	62.20	62.33	61.76	39.6	Spreading	9	7.1	1.0
68	do	222.7	210	106.0	5.87	7.06	8.45	9.29	9.52	60.76	62.27	61.00	46.4	Alternate	8	5.3	.6
65	Indiana No. 2	193.4	210	92.1	6.09	7.29	8.02	9.14	9.53	61.11	63.79	62.19	33.2	do	8	6.3	.6
162	Indiana No. 3	191.2	210	91.1	6.14	7.10	8.11	9.72	10.15	66.60	69.54	67.12	25.8	do	6	4.4	1.2
151	Indiana No. 4	169.6	210	80.8	5.74	6.64	7.74	9.26	9.57	62.29	64.37	62.41	12.8	do	8	4.3	1.3
165	do	186.7	210	88.9	5.94	6.94	8.06	9.67	10.43	65.02	70.13	67.68	16.1	do	6	4.4	1.7
166	do	156.9	210	74.7	5.57	6.46	7.58	9.61	9.86	64.69	66.38	62.60	2.0	do	6	4.4	.6
154	do	200.4	210	95.3	6.45	7.55	8.86	9.71	9.86	63.97	64.96	63.75	19.2	do	7	4.0	2.0
153	Indiana No. 5	186.0	210	88.6	6.26	7.30	8.24	9.37	9.61	63.05	64.67	63.25	39.0	do	8	4.2	.9

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Horsepower. Developed on test.	Horsepower. Builder's rating.	Horsepower. Per cent of rated horsepower developed.	Economic results (pounds of water evaporated per pound of fuel). Apparent under actual conditions as fired.	Economic results. Equivalent from and at 212° F. As fired.	Economic results. Equivalent from and at 212° F. Dry.	Economic results. Equivalent from and at 212° F. Combustible determined from— Actual weight of ash.	Economic results. Equivalent from and at 212° F. Combustible determined from— Analysis of ash and coal.	Efficiency (per cent) of— Boiler, from actual weight of ash.	Efficiency (per cent) of— Boiler, from analysis of ash and coal.	Efficiency (per cent) of— Boiler and grate.	Smoke (per cent of black).	Kind of firing.	Methods of firing. Thickness of fire (inches).	Methods of firing. Interval between. Normal firings (minutes).	Methods of firing. Interval between. Times of leveling or breaking up (hours).
1	2	72(65)	73(66)	74(67)	75(68)	76(69)	77(70)	78(71)	79(71.1)	80(72)	81(72.1)	82(73)	83(77)	84(80)	85(81)	86(82)	87(83)
155	Indiana No. 5	170.8	210	81.3	6.32	7.36	8.35	9.57	9.91	63.92	66.19	64.27	17.8	Alternate	8	4.4	0.9
156	....do	182.8	210	87.0	6.20	7.23	8.13	9.32	9.49	62.00	63.13	61.67	32.0	....do	8	4.2	1.1
157	Indiana No. 6	178.4	210	84.9	6.30	7.30	8.16	9.57	9.72	63.36	64.36	63.02	18.6	....do	8	4.3	1.1
159	....do	203.0	210	96.7	6.15	7.15	8.06	8.96	9.18	58.93	60.37	59.46	43.4	....do	6	3.9	.9
158	Indiana No. 7A	203.4	210	96.9	6.80	7.95	8.72	9.69	9.83	63.79	64.71	63.56	45.4	....do	8	4.1	1.7
288	....do	177.5	210	84.5	6.49	7.78	8.70	9.74	10.04	64.10	66.08	64.26	.0	....do	8	4.7	1.6
164	Indiana No. 7B	158.5	210	75.5	6.05	7.06	7.91	9.02	9.14	60.00	60.89	59.49	15.2	....do	5	5.0	.5
176	....do	165.0	210	78.6	6.27	7.27	8.02	9.08	9.32	60.25	62.18	60.94	16.0	....do	5	4.5	.6
182	Indiana No. 8	189.4	210	90.2	6.34	7.38	8.15	9.18	9.52	60.39	62.63	61.31	29.2	....do	7	4.4	2.0
183	....do	169.4	210	80.7	6.43	7.48	8.36	9.53	9.85	62.88	64.99	64.14	19.2	....do	6	4.9	.8
185	....do	187.0	210	89.0	6.24	7.28	8.10	9.33	9.63	61.15	63.11	61.97	19.4	....do	7	4.3	1.7
184	....do	203.7	210	97.0	6.61	7.72	8.76	9.81	9.94	64.74	65.60	64.62	44.8	....do	7	4.0	2.5
168	Indiana No. 9A	213.0	210	101.4	6.37	7.44	8.45	9.78	10.17	65.76	68.38	66.99	40.2	....do	6	4.2	1.2
169	....do	192.1	210	91.5	6.46	7.54	8.62	9.98	10.18	66.86	68.20	66.88	18.8	....do	5	4.4	.8
174	Indiana No. 9B	184.6	210	87.9	6.23	7.24	8.19	9.31	9.50	62.01	63.28	62.08	9.6	....do	7	4.6	1.1
334	Indiana Nos. 9A and 9B	237.0	210	112.9	6.14	7.38	8.45	9.58	9.70	63.99	64.79	63.76	50.0	....do	12	4.1	.8
167	Indiana No. 10	208.8	210	99.4	6.63	7.74	8.66	9.77	10.01	65.00	66.60	65.00	36.6	....do	7	4.2	1.3
177	....do	221.2	210	105.3	6.25	7.27	8.17	8.75	8.89	57.80	58.72	58.03	46.6	Spreading	7	5.7	1.7
233	Indiana No. 11	215.2	210	102.5	6.61	7.88	8.94	10.00	9.98	65.49	65.36	64.32	28.4	Alternate	5	3.7	1.6
234	....do	191.9	210	91.4	6.71	7.99	8.99	9.91	10.06	64.96	65.94	65.11	30.5	....do	7	4.2	1.9
235	....do	201.9	210	96.1	6.66	7.94	9.03	9.84	10.00	64.31	65.36	64.72	28.6	....do	6–8	3.9	1.4
299	Indiana No. 12	195.5	210	93.1	5.85	7.02	8.05	9.46	9.78	63.22	65.36	64.16	28.2	....do	5	4.0	.9
300	....do	218.1	210	103.9	5.99	7.20	8.22	9.56	10.02	64.07	67.15	65.44	31.4	....do	5	3.6	1.7
310	....do	205.4	210	97.8	6.69	8.00	9.18	10.34	10.29	68.39	68.06	66.80	16.0	....do	5	2.9	1.9
432	Indiana No. 13	201.1	210	95.8	6.45	7.50	8.60	10.00	10.23	66.56	68.09	66.46	10.0	....do	8	2.6	1.3
433	....do	193.4	210	92.1	5.97	6.93	8.02	9.79	9.70	65.01	64.41	61.58	7.0	....do	9	3.5	.9

430	Indiana No. 14	178.3	210	84.9	6.30	7.35	8.03	9.57	9.80	64.98	66.54	64.70	11.0	....do	8	3.9	1.1
431	....do	177.7	210	84.6	6.10	7.09	7.83	9.42	10.42	64.19	71.01	68.01	12.5	....do	9	4.0	1.4
428	Indiana No. 15	200.8	210	95.6	6.34	7.39	8.50	9.52	9.71	63.06	64.31	62.66	11.5	....do	8	3.4	1.2
429	....do	184.5	210	87.9	6.43	7.49	8.59	9.61	9.73	63.63	64.43	62.81	.0	....do	8	3.8	1.1
426	Indiana No. 16	187.1	210	89.1	6.47	7.51	8.26	9.51	9.83	64.14	66.30	64.59	16.5	....do	7	3.6	1.0
427	....do	165.0	210	78.6	6.30	7.32	8.14	9.43	9.72	63.37	65.32	63.76	6.0	....do	8	3.8	1.0
441	Indiana No. 17	190.4	210	90.7	6.41	7.46	8.26	9.51	9.53	64.03	64.17	61.70	15.0	....do	7	3.9	1.1
442	....do	164.2	210	78.2	5.85	6.83	7.77	9.30	9.35	62.72	63.05	59.91	8.0	....do	7	4.3	.8
435	Indiana No. 18B	213.0	210	101.4	6.70	7.79	8.85	9.84	9.86	64.55	64.68	63.10	14.0	....do	5	3.4	1.7
436	....do	230.3	210	109.7	6.76	7.89	8.97	10.00	10.05	65.45	65.77	63.61	20.0	....do	5	3.1	1.2
464	Indiana No. 19	192.8	210	91.8	5.92	7.15	7.86	9.02	9.62	60.49	64.51	63.62	5.5	....do	6	3.5	.9
10	Indian Territory No. 1	194.7	210	91.8	6.76	7.98	8.64	10.11	10.51	66.11	68.73	65.01	31.6	....do	8	5.0	0.6
20	Indian Territory No. 2	212.9	210	101.4	6.88	8.11	8.42	9.58	9.64	61.97	62.36	60.61	55.2	....do	8	5.2	.6
417	Indian Territory No. 2B	190.0	210	90.5	7.57	8.83	9.09	10.42	10.62	66.81	68.10	64.86	19.5	....do	3	3.7	1.3
418	....do	199.4	210	95.0	7.81	9.10	9.38	10.58	10.65	67.92	68.38	66.02	15.5	....do	5	3.7	1.4
455	....do	196.4	210	93.5	6.82	8.17	8.39	9.54	9.52	60.54	60.41	58.05	8.0	....do	5	4.1	1.0
453	....do	220.8	210	105.1	7.60	9.12	9.42	10.71	10.80	69.08	69.66	66.46	4.5	....do	6	3.8	1.1
456	....do	223.8	210	106.6	7.23	8.65	8.90	9.89	10.00	63.10	63.81	62.02	8.5	....do	6	3.9	1.0
32	Indian Territory No. 3	205.9	210	98.1	6.58	7.78	8.17	9.71	9.55	64.28	63.22	60.67	37.0	....do	8	5.3	.5
52	Indian Territory No. 4	186.1	210	88.6	5.94	7.06	7.53	8.55	8.94	59.14	61.84	60.46	42.0	Spreading	9	6.6	.3
437	Indian Territory No. 8	201.7	210	96.0	7.45	8.64	8.89	10.22	10.08	65.19	64.29	61.62	7.0	Alternate	7	3.9	1.1
449	Indian Territory No. 9	203.7	210	97.0	7.51	8.96	9.31	10.62	10.62	65.20	65.20	61.24	3.0	....do	6	4.0	.5
450	....do	214.6	210	102.2	8.00	9.56	9.89	....	11.10	....	67.77	65.41	.0	....do	7	4.3	1.7
45	Iowa No. 1	197.7	210	94.2	5.55	6.61	7.24	9.04	9.37	60.96	63.19	61.10	50.4	....do	8	6.0	.5
67	Iowa No. 2	192.7	210	91.8	5.01	6.00	7.05	8.54	9.04	58.23	61.64	59.22	46.8	....do	8	5.6	.4
49	Iowa No. 3	189.3	210	90.2	5.17	6.14	7.02	8.29	9.00	56.34	61.16	58.09	34.8	Spreading	8	6.8	.5
47	Iowa No. 4	167.3	210	79.7	5.20	6.15	7.11	8.47	8.95	57.78	61.05	58.79	41.0	....do	8	7.2	.8
66	....do	184.5	210	87.9	5.41	6.43	7.43	8.62	9.02	56.85	59.49	57.18	27.3	Alternate	10	....	.3
55	Iowa No. 5	204.8	210	97.5	5.28	6.30	7.50	8.73	9.16	59.23	62.10	60.54	49.5	....do	9	6.3	.4
601	Jamestown No. 1	193.0	210	91.9	7.70	8.94	9.06	10.61	10.97	66.72	68.98	67.77	3.4	Mechanical	20	....	4.0
602	....do	217.4	210	103.5	7.07	8.32	8.46	9.78	10.36	62.28	65.97	64.80	2.9	....do	22	....	2.7
603	Jamestown No. 3	242.2	210	115.3	8.00	9.32	9.50	10.13	10.49	61.71	63.90	63.03	3.9	....do	....	....	1.4
604	....do	268.6	210	127.9	8.41	9.89	10.07	10.69	11.23	65.29	68.59	67.75	5.3	....do	20	....	4.0
605	....do	223.3	210	106.3	7.92	9.30	9.48	10.17	10.49	61.96	63.91	63.47	2.0	....do	22	....	4.1
606	....do	164.5	210	78.3	8.66	9.98	10.21	11.19	11.25	68.23	68.61	66.76	8.6	Alternate	11	5.4	1.1
607	....do	169.2	210	80.6	8.79	10.22	10.45	11.42	11.30	69.67	68.94	67.19	8.4	....do	8	5.3	.6
608	Jamestown No. 4	170.2	210	81.0	8.23	9.57	9.78	10.40	10.54	64.06	64.91	63.42	5.5	....do	10	5.0	.8
609	....do	271.9	210	129.5	8.13	9.57	9.79	....	10.57	....	64.93	63.69	6.2	....do	9	4.0	.6
610	....do	325.0	210	154.8	8.32	9.81	10.02	10.56	10.80	64.81	66.29	65.40	5.6	....do	8	3.7	.7
611	....do	121.1	210	57.7	8.76	10.34	10.56	11.11	11.02	68.15	67.60	67.48	.8	Mechanical	22	....	.8
612	....do	123.7	210	58.9	8.53	10.09	10.31	10.84	10.84	66.52	66.52	66.48	1.1	....do	21	....	1.3
613	....do	118.4	210	56.4	8.03	9.52	9.70	10.20	10.60	62.59	65.04	64.97	1.9	....do	21	....	1.5
614	....do	115.0	210	54.8	8.74	10.36	10.55	11.10	11.36	67.99	69.58	69.54	.0	....do	19	....	1.0
615	....do	148.5	210	70.7	8.69	10.29	10.48	11.03	11.15	67.70	68.44	68.27	.0	....do	20	....	2.3
616	....do	159.1	210	75.8	8.59	10.18	10.34	10.88	10.86	66.74	66.62	66.56	.5	....do	21	....	1.5
617	....do	149.9	210	71.4	8.85	10.52	10.72	11.54	11.19	70.77	68.62	68.49	1.2	....do	19	....	1.5
618	....do	154.3	210	73.5	9.36	11.13	11.35	12.22	12.02	74.93	73.71	73.64	1.1	....do	22	....	1.3
619	....do	157.1	210	74.8	9.02	10.71	10.91	11.75	11.42	72.04	70.01	69.91	.0	....do	21	....	1.1
627	Jamestown No. 6	276.2	210	131.5	8.73	10.42	10.66	11.28	11.28	69.13	69.13	68.93	1.3	....do	21	....	2.3
630	....do	174.5	210	83.1	8.64	10.31	10.55	11.19	11.19	68.47	68.47	68.13	1.0	....do	20	....	1.3
631	....do	367.4	210	175.0	8.58	10.19	10.48	11.13	11.13	68.11	68.11	67.60	3.9	....do	21	....	1.3
620	Jamestown No. 7	199.2	210	94.9	8.93	10.62	10.81	11.36	11.36	69.41	69.41	69.32	.9	....do	20	....	1.1

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Horsepower.			Economic results (pounds of water evaporated per pound of fuel).					Efficiency (per cent) of—			Smoke (per cent of black).	Kind of firing.	Methods of firing.		
		Developed on test.	Builder's rating.	Per cent of rated horsepower developed.	Apparent under actual conditions as fired.	Equivalent from and at 212° F.				Boiler, from actual weight of ash.	Boiler, from analysis of ash and coal.	Boiler and grate.			Thickness of fire (inches).	Interval between.	
						As fired.	Dry.	Combustible determined from—								Normal firings (minutes).	Times of leveling or breaking up (hours).
								Actual weight of ash.	Analysis of ash and coal.								
1	2	72(65)	73(66)	74(67)	75(68)	76(69)	77(70)	78(71)	79(71.1)	80(72)	81(72.1)	82(73)	83(77)	84(80)	85(81)	86(82)	87(83)
621	Jamestown, No. 7	196.3	210	93.0	8.09	9.62	9.88	10.38	10.38	63.44	63.44	63.37	0.8	Mechanical	18	....	2.3
623	.....do	264.6	210	126.0	8.63	10.28	10.46	11.12	11.12	68.00	68.00	67.79	2.2	.....do	23	....	3.0
624	.....do	261.8	210	124.7	7.95	9.47	9.63	10.11	10.11	61.83	61.83	61.77	1.8	.....do	22	....	4.0
625	.....do	220.5	210	105.0	8.80	10.47	10.70	11.37	11.37	69.62	69.62	69.52	2.2	.....do	20	....	2.0
626	.....do	260.4	210	124.0	8.21	9.78	9.97	10.53	10.53	64.51	64.51	64.49	2.3	.....do	18	....	4.0
639	Jamestown No. 11	214.6	210	102.2	8.33	9.94	10.30	10.87	11.16	65.93	67.69	66.62	8.2	Alternate	10	5.2	.5
6	Kansas No. 1	158.2	210	75.3	6.63	7.63	8.11	9.09	9.61	58.35	61.69	58.90	23.6	.....do	10	6.0	.8
7	.....do	184.0	210	87.4	7.09	8.22	8.63	10.06	10.45	65.31	67.85	65.65	14.4	.....do	6	5.0	1.9
5	Kansas No. 2	181.5	210	86.4	6.79	7.82	8.17	9.25	....	59.77	....	64.98	20.0	.....do	10	5.0	2.0
13	.....do	210.1	210	100.0	7.11	8.38	8.90	9.99	10.18	62.73	63.98	61.53	55.0	.....do	10	5.0	1.0
488	Kansas No. 2B	202.8	210	96.6	6.19	7.48	7.84	10.06	10.20	64.90	65.80	64.34	.0	.....do	7	3.4	1.0
487	.....do	182.2	210	86.8	5.97	7.22	7.97	9.91	10.11	63.59	64.88	63.12	2.5	.....do	9	4.7	1.2
495	.....do	224.2	210	106.8	7.18	8.67	9.39	10.38	10.53	66.02	66.97	65.66	1.5	.....do	7	4.3	1.2
3	Kansas No. 3	169.6	210	81.0	6.61	7.58	7.69	8.92	9.22	57.10	59.03	57.08	17.2	.....do	10	5.5	....
4	.....do	148.8	210	70.9	6.55	7.52	7.69	8.86	9.26	56.58	59.14	56.28	45.0	.....do	8	7.0	2.0
58	Kansas No. 4	165.5	210	78.8	6.14	7.32	7.75	9.00	9.49	59.29	62.52	60.37	34.4	Spreading	7	8.0	.6
72	Kansas No. 5	215.2	210	102.5	7.04	8.50	8.88	10.11	10.52	65.08	67.67	66.24	32.8	Alternate	8	6.0	.5
311	Kansas No. 6	172.6	210	82.2	6.03	7.23	7.88	9.56	9.89	62.13	64.28	61.65	7.0	.....do	6	4.4	1.2
323	.....do	223.9	210	106.6	6.24	7.53	8.52	10.01	9.92	64.89	64.31	62.64	38.3	.....do	8	3.8	1.8
60	Kentucky No. 1	212.3	210	101.1	7.33	8.80	9.06	9.81	9.94	61.94	62.76	60.91	64.8	.....do	11	5.4	.4
255	Kentucky No. 1C	194.6	210	92.7	7.53	8.94	9.34	9.93	10.08	62.66	63.61	62.58	28.8	.....do	10	4.5	.8
263	.....do	165.7	210	78.9	7.82	9.38	9.81	10.48	10.83	66.22	68.44	66.38	13.6	.....do	14	5.2	1.4
265	.....do	162.2	210	77.2	7.74	9.18	9.57	10.23	10.44	64.62	65.95	64.88	12.0	.....do	5	5.4	.9
57	Kentucky No. 2	208.5	210	99.3	6.29	7.53	8.16	9.16	9.23	60.00	60.45	58.92	47.4	Spreading	7	7.3	.7
76	.....do	207.1	210	98.6	6.21	7.48	8.06	9.17	9.41	60.77	62.37	60.96	51.4	Spreading, alternate.	10	6.1	.6

64	Kentucky No. 3	211.5	210	100.7	6.87	7.62	8.27	9.22	9.49	60.95	62.73	61.26	47.6	Alternate	8	5.6	.8
62	Kentucky No. 4	211.7	210	100.8	6.46	7.78	8.21	9.44	9.86	60.94	63.65	61.28	54.2	do	8	5.5	.6
276	Kentucky No. 5	234.3	210	111.6	8.01	9.68	10.10	10.47	10.62	66.65	67.61	66.94	...	do	...	...	4.9
277	do	188.4	210	89.7	8.28	9.86	10.42	11.08	11.13	70.65	70.96	69.35	...	do	4	4.3	1.3
270	Kentucky No. 6	187.7	210	89.4	7.91	9.50	9.96	10.42	10.42	67.39	67.39	66.59	19.4	do	4	5.0	3.3
271	do	183.9	210	87.6	7.33	9.37	9.86	10.24	10.33	66.23	66.81	65.61	...	do	6	5.0	2.5
278	Kentucky No. 7	158.1	210	75.3	6.67	8.01	8.84	10.28	10.44	68.34	69.75	67.95	...	do	5-6	4.8	1.6
279	do	143.7	210	68.4	6.45	7.68	8.38	9.94	10.05	66.35	67.08	64.71	...	do	5	4.3	1.0
434	Kentucky No. 8	209.9	210	100.0	7.35	8.56	9.08	9.96	10.12	62.99	64.01	62.52	34.0	do	5	4.0	1.5
443	do	218.6	210	104.1	7.44	8.73	9.24	10.10	10.36	63.76	65.40	63.54	9.0	do	5	4.0	.8
462	Kentucky No. 9B	217.4	210	103.5	6.55	7.92	8.61	9.90	9.97	65.08	65.54	63.55	19.0	do	5	3.4	.9
222	Maryland No. 1	168.3	210	80.1	7.59	8.90	9.06	10.39	10.60	63.99	65.28	63.96	8.2	do	9	5.0	.7
221	do	201.3	210	95.9	7.86	9.34	9.70	11.01	11.14	67.76	68.56	67.17	.0	do	5	5.0	1.4
282	do	195.7	210	93.2	7.75	9.22	9.55	10.77	10.98	66.35	67.64	65.72	7.5	do	6	5.2	1.0
490	Maryland No. 2	239.2	210	113.9	8.16	9.87	10.11	10.96	11.24	66.83	68.54	67.26	4.8	do	9	3.6	.7
493	do	254.5	210	121.2	7.87	9.52	10.22	11.25	11.35	68.57	69.18	67.71	.0	do	10	4.0	1.8
518	do	143.6	210	68.4	8.45	10.25	10.70	12.71	12.23	77.70	74.77	70.21	7.5	do	10	7.1	1.8
12	Missouri No. 1	207.4	210	98.8	6.23	7.35	7.92	9.79	10.20	63.54	56.26	63.18	24.6	do	9	4.7	1.5
23	do	191.2	210	91.0	6.34	7.48	7.99	9.48	9.70	61.29	62.71	60.86	18.4	do	10	5.2	2.0
15	do	207.0	210	98.6	6.66	7.83	8.50	9.65	9.84	62.26	63.49	62.32	34.0	do	8	4.5	1.0
37	Missouri No. 2	208.2	210	99.1	5.17	6.16	7.08	8.92	9.24	60.52	62.69	59.45	30.4	Spreading	7	6.7	.6
44	do	172.5	210	82.1	5.40	6.42	7.26	8.65	9.35	58.45	63.17	60.68	51.0	do	7	8.3	.5
78	Missouri No. 3	149.5	210	71.2	3.94	4.74	5.82	8.10	9.08	56.61	63.11	58.94	...	do	6	6.9	.4
77	do	189.7	210	90.3	4.89	5.89	7.43	8.44	8.63	57.90	59.10	56.98	32.0	do	7	7.1	.5
70	Missouri No. 4	214.1	210	102.0	6.44	7.75	8.83	9.46	9.61	60.28	61.24	60.06	56.0	Alternate	8	5.6	.7
319	Missouri No. 5	164.1	210	78.1	5.39	6.49	7.49	9.05	9.36	61.18	63.28	61.57	7.2	do	8	4.2	.9
320	do	198.8	210	94.7	5.54	6.67	7.60	9.06	9.60	61.15	64.87	62.90	.0	do	10	3.6	.6
326	Missouri No. 6	204.6	210	97.4	5.71	6.88	7.98	9.22	9.64	61.80	64.61	63.40	6.4	do	6	3.6	1.2
327	do	215.7	210	102.7	5.75	6.93	7.96	8.94	9.30	59.32	61.70	60.64	17.0	do	6	3.9	1.4
329	Missouri No. 7A	206.7	210	98.4	5.53	6.64	8.03	9.15	9.32	61.10	62.24	61.26	18.5	do	8	3.5	1.9
330	do	241.4	210	115.0	5.42	6.52	7.92	9.37	9.29	62.57	62.03	60.49	27.5	do	8	3.3	1.4
332	Missouri No. 7B	271.8	210	129.4	4.93	5.94	7.22	8.04	8.36	54.48	56.64	55.92	42.5	do	10	4.1	1.2
486	Missouri No. 10	193.3	210	92.0	5.25	6.36	6.66	8.07	8.41	53.86	56.13	55.19	2.5	do	8	3.5	.8
470	Montana No. 2	238.0	210	113.3	5.75	6.93	7.64	9.24	9.71	64.81	68.11	65.54	18.0	do	10	3.3	.9
477	Montana No. 3	241.9	210	115.2	5.75	6.92	7.63	9.26	9.32	65.36	65.78	63.37	12.5	do	7	3.0	2.2
27	New Mexico No. 1	206.3	210	98.5	5.53	6.53	7.41	8.12	8.58	56.22	59.30	56.91	64.0	do	6	5.0	.5
28	New Mexico No. 2	198.5	210	94.5	4.89	5.77	6.41	8.56	8.53	58.75	58.54	53.98	21.4	Spreading	8	4.7	.5
30	do	185.8	210	88.4	5.67	6.70	7.19	9.44	9.54	61.22	61.89	56.73	16.4	Alternate	8	5.0	.7
396	New Mexico No. 3A	227.3	210	108.2	6.84	8.00	8.23	9.90	10.36	64.21	67.19	64.61	14.5	do	9	3.5	1.4
389	New Mexico No. 3B	206.9	210	98.5	7.02	8.16	8.42	9.90	10.54	64.29	68.45	66.58	.0	do	9	3.9	1.7
391	do	241.0	210	114.8	7.18	8.40	8.61	10.16	10.66	65.93	69.18	67.59	24.5	do	9	3.4	1.4
392	do	250.4	210	119.2	7.08	8.26	8.68	9.83	10.16	63.35	65.48	64.19	26.0	do	8	3.3	1.2
397	New Mexico No. 4A	218.1	210	103.9	6.79	7.97	8.16	9.46	9.84	61.40	63.86	62.25	16.5	do	8	3.7	1.7
398	do	227.1	210	108.1	7.23	8.47	8.81	9.89	10.17	64.02	65.83	64.70	21.0	do	6	3.8	1.7
395	New Mexico No. 4B	211.3	210	100.6	6.96	8.14	8.43	9.66	10.10	62.28	65.12	63.37	18.0	do	10	3.6	1.3
387	New Mexico No. 5	208.2	210	99.1	7.03	8.19	8.39	9.75	10.23	62.16	65.22	63.39	20.5	do	10	3.6	1.2
33	North Dakota No. 1	108.9	210	51.9	2.96	3.46	5.40	6.10	6.87	47.25	53.22	50.13	.0	Spreading	4	6.7	.4
206	North Dakota No. 3	190.5	210	90.7	3.52	4.13	6.45	6.97	7.47	53.61	57.46	56.44	.0	do	6	6.0	2.9
191	Ohio No. 1	175.6	210	83.6	6.36	7.44	8.05	9.56	10.04	64.93	68.19	66.42	26.0	Alternate	7	4.4	1.4
192	do	189.2	210	90.1	6.48	7.58	8.31	9.30	9.42	62.21	63.02	61.54	...	do	7	4.6	1.7
193	Ohio No. 2	168.6	210	80.3	6.03	7.06	7.75	9.21	9.57	61.91	64.38	61.40	27.6	do	6	4.5	1.2
197	do	177.3	210	84.4	6.32	7.43	8.16	8.96	9.28	60.38	62.54	60.09	32.2	do	7	4.6	1.4
203	Ohio No. 3	220.5	210	105.0	6.95	8.17	8.97	9.91	10.01	66.03	66.70	65.44	43.4	do	6	4.2	1.9

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Horsepower. Developed on test.	Horsepower. Builder's rating.	Horsepower. Per cent of rated horsepower developed.	Economic results (pounds of water evaporated per pound of fuel). Apparent under actual conditions as fired.	Equivalent from and at 212° F. As fired.	Equivalent from and at 212° F. Dry.	Combustible determined from— Actual weight of ash.	Combustible determined from— Analysis of ash and coal.	Efficiency (per cent) of— Boiler, from actual weight of ash.	Efficiency (per cent) of— Boiler, from analysis of ash and coal.	Efficiency (per cent) of— Boiler and grate.	Smoke (per cent of black).	Kind of firing.	Methods of firing. Thickness of fire (inches)	Interval between. Normal firings (minutes).	Interval between. Times of leveling or breaking up (hours).
1	2	72(65)	73(66)	74(67)	75(68)	76(69)	77(70)	78(71)	79(71.1)	80(72)	81(72.1)	82(73)	83(77)	84(80)	85(81)	86(82)	87(83)
188	Ohio No. 4	199.6	210	95.0	7.08	8.31	8.62	9.66	9.89	62.48	63.97	62.26	33.6	Alternate	8	4.8	1.3
201	....do	195.7	210	93.2	7.37	8.66	9.00	10.08	10.32	64.60	66.14	64.17	25.8	....do	8	4.7	2.0
202	....do	209.0	210	99.5	7.46	8.78	9.10	10.11	10.48	65.42	67.82	65.71	40.6	....do	8	4.5	1.2
219	....do	188.7	210	89.9	7.44	8.77	9.14	10.02	10.17	64.29	65.25	63.55	38.3	....do	6	4.8	3.3
220	....do	195.7	210	93.2	7.26	8.56	8.95	9.74	9.84	62.55	63.19	61.80	39.2	....do	5	4.5	2.0
221	....do	193.5	210	92.1	7.32	8.61	9.00	9.80	....	62.93	....	62.14	22.8	....do	4	4.6	1.8
186	Ohio No. 5	223.5	210	106.4	7.25	8.47	8.85	9.62	9.84	62.26	63.68	62.45	54.8	....do	5	4.3	1.7
187	....do	238.8	210	113.7	7.20	8.45	8.87	9.58	9.96	62.02	64.48	63.60	28.2	....do	6	4.2	1.3
189	....do	211.9	210	100.9	7.52	8.81	9.25	10.12	10.34	65.64	67.07	66.01	34.4	....do	8	4.6	1.4
190	....do	217.8	210	103.7	7.39	8.67	9.07	9.83	10.24	63.70	66.35	65.12	52.0	....do	8	4.4	1.8
284	Ohio No. 6.a	170.8	210	81.3	7.27	8.71	9.04	10.25	10.60	66.73	69.01	67.29	13.1	....do	4	5.1	1.2
253	....do	166.8	210	79.4	7.32	8.73	9.02	9.66	9.93	62.34	64.08	62.66	23.2	....do	10	4.9	2.1
268	Ohio No. 7	168.7	210	80.3	7.03	8.40	9.00	10.10	10.37	66.31	68.09	66.62	25.6	....do	10	4.8	2.5
269	....do	190.9	210	90.9	6.85	8.20	8.76	9.73	10.06	63.98	66.15	64.68	36.8	....do	10	4.4	2.1
287	Ohio No. 8	202.3	210	96.3	6.86	8.22	9.01	9.73	10.08	64.92	67.26	66.24	15.2	....do	7	4.0	3.2
246	Ohio No. 9A	195.6	210	93.1	7.20	8.57	9.10	9.80	10.06	64.17	65.88	65.06	38.4	....do	8	4.4	2.7
249	....do	172.4	210	82.1	7.00	8.33	8.90	9.71	9.96	63.50	65.14	64.19	19.3	....do	5	4.4	1.2
250	....do	169.5	210	80.7	7.26	8.66	9.22	10.10	10.31	66.09	67.46	66.60	....	....do	5	4.7	2.0
252	....do	184.5	210	87.9	7.11	8.49	9.03	9.69	10.10	63.34	66.02	65.05	32.5	....do	9	4.6	2.2
224	Ohio No. 9B	184.4	210	87.8	6.32	7.48	8.12	9.59	9.97	64.07	66.61	64.70	22.4	....do	8	4.4	1.4
241	....do	194.7	210	92.7	7.18	8.56	9.30	9.96	10.17	65.75	67.13	66.51	39.6	....do	6	4.6	2.7
243	....do	194.9	210	92.8	7.48	8.93	9.11	9.83	9.98	65.62	66.62	65.78	39.1	....do	7	4.7	1.6
244	....do	192.1	210	91.5	7.41	8.82	9.04	9.76	9.86	65.15	65.82	65.05	....	....do	7	4.6	1.5
469	Ohio No. 10	250.1	210	119.1	7.38	8.90	9.28	10.20	10.39	67.30	68.56	67.43	17.0	....do	7	3.4	2.0
474	Ohio No. 11	215.1	210	102.4	7.04	8.47	8.79	10.32	10.14	67.58	66.41	64.72	8.5	....do	8	3.7	.9
475	....do	215.4	210	102.5	7.08	8.55	8.86	10.20	10.21	67.53	67.60	66.38	11.5	....do	7	3.8	1.5

483	Ohio No. 12	247.0	210	117.6	7.28	8.81	9.14	10.31	10.40	66.90	67.48	65.96	9.0	do.	8	3.4	1.8
1	Pennsylvania No. 1	166.9	210	79.5	7.70	8.94	9.04	9.46	9.99	57.64	60.87	59.55	......	do.	10	10.5	......
2	Pennsylvania No. 2	191.2	210	91.0	8.48	9.73	9.79	10.12	10.60	61.85	64.78	63.69	......	do.	12	7.0	......
36	Pennsylvania No. 3	184.5	210	87.9	6.73	8.01	8.26	10.43	10.63	64.57	65.81	60.02	1.8	do.	7	6.0	.8
74	Pennsylvania No. 4	210.0	210	100.0	7.70	9.30	9.58	10.46	10.54	64.67	65.17	64.24	29.2	do.	12	6.0	.4
207	do.	200.7	210	95.6	8.10	9.47	9.70	10.77	11.09	68.27	69.01	67.01	24.0	do.	7	4.7	.8
208	do.	181.1	210	86.2	8.23	9.62	9.84	11.11	11.36	69.08	70.68	68.26	9.6	do.	7	5.0	.6
209	do.	180.7	210	86.0	8.02	9.38	9.61	10.71	10.98	66.62	68.29	66.52	11.6	do.	8	4.9	.6
286	Pennsylvania No. 5	201.4	210	95.9	8.29	9.92	10.35	11.17	11.40	70.52	71.97	71.25	15.1	do.	6	5.0	1.7
194	do.	207.5	210	98.8	7.93	9.30	9.59	10.13	10.21	63.95	64.46	63.76	31.8	do.	8	4.8	1.3
195	do.	203.4	210	96.9	7.97	9.36	9.65	10.27	10.36	64.76	65.83	63.97	43.8	do.	......	4.7	1.1
217	Pennsylvania No. 6	203.9	210	97.1	7.46	8.79	9.01	10.05	10.52	63.42	66.39	64.91	37.8	do.	8	4.4	2.0
218	do.	183.5	210	87.4	7.74	9.11	9.37	10.55	10.94	66.76	69.23	68.18	21.8	do.	10	4.9	2.0
333	do.	222.3	210	105.9	6.96	8.36	8.77	10.29	10.33	65.88	65.64	64.34	15.5	do.	12	4.9	.8
198	Pennsylvania No. 7	183.8	210	87.5	7.55	8.87	9.18	10.65	10.85	65.55	66.78	64.96	7.6	do.	10	5.1	.8
307	do.	178.6	210	85.0	7.34	8.76	9.29	10.91	11.16	66.97	68.51	66.68	8.0	do.	10	4.5	.9
199	do.	186.0	210	88.6	7.64	8.99	9.44	10.74	10.88	66.37	67.24	65.93	10.8	do.	6	5.1	.6
236	Pennsylvania No. 8	172.3	210	82.0	8.51	10.12	10.37	11.09	11.20	67.35	68.02	67.27	.0	do.	12	5.2	1.1
237	do.	174.2	210	83.0	8.27	9.85	10.17	10.87	11.02	66.03	66.94	66.06	.0	do.	12	5.2	.8
238	do.	172.4	210	82.1	8.44	10.05	10.42	11.05	11.29	67.11	68.57	67.86	......	do.	12	5.2	.7
239	do.	181.6	210	86.5	7.98	9.52	9.75	10.45	10.71	63.54	65.18	64.10	......	do.	12	5.1	.8
242	do.	172.0	210	81.9	8.52	10.17	10.22	10.95	11.15	67.04	68.26	67.19	.0	do.	12	6.7	.7
227	Pennsylvania No. 10	203.7	210	97.0	8.28	9.80	10.12	10.95	11.03	68.96	69.46	68.15	32.4	do.	12	5.0	2.5
228	do.	190.4	210	90.7	8.35	9.85	10.14	10.98	11.09	69.16	69.86	68.36	25.2	do.	12	4.8	2.0
229	do.	222.4	210	105.9	7.94	9.47	9.69	10.35	10.49	65.07	65.95	64.84	33.9	do.	9	4.3	1.4
472	Pennsylvania No. 15	176.9	210	84.2	7.27	8.76	8.93	10.49	10.57	65.17	65.66	62.81	4.0	do.	8	4.2	.4
473	do.	191.5	210	91.2	7.65	9.22	9.45	10.95	10.85	67.07	66.46	64.09	4.5	do.	8	3.8	.5
467	do.	208.0	210	99.0	7.98	9.65	10.04	11.35	11.30	70.39	70.08	68.00	5.5	do.	7	3.8	1.0
468	Pennsylvania No. 16	221.9	210	105.7	7.78	9.40	9.92	10.86	11.03	67.17	68.22	67.28	4.0	do.	9	4.2	1.4
471	do.	207.7	210	98.9	7.59	9.15	9.55	10.97	11.03	68.92	69.29	66.16	8.0	do.	7	3.8	.6
496	Pennsylvania No. 17	213.7	210	101.8	7.28	8.78	9.09	10.50	10.76	65.53	67.15	65.24	7.0	do.	5	3.9	.5
506	do.	205.8	210	98.0	7.02	8.51	8.76	9.92	10.16	61.96	63.46	62.00	9.0	do.	9	3.9	.5
499	Pennsylvania No. 18	240.8	210	114.7	7.54	9.14	9.52	10.47	10.72	64.36	65.90	65.11	.0	do.	9	3.5	2.1
515	do.	236.4	210	112.6	7.38	8.95	9.52	10.41	10.62	63.88	65.17	64.33	.0	do.	9	4.3	1.0
498	Pennsylvania No. 19	224.3	210	106.8	7.48	9.05	9.35	10.55	10.48	66.28	65.84	63.91	4.5	do.	5	4.2	1.6
508	do.	238.7	210	113.7	7.58	9.20	9.69	10.65	10.79	66.36	67.23	65.58	.0	do.	11	4.2	.7
512	Pennsylvania No. 20	226.1	210	107.7	7.70	9.32	9.65	10.64	10.76	64.42	65.14	64.29	.0	do.	11	4.6	1.1
514	do.	263.2	210	125.3	6.54	7.91	8.14	8.76	9.06	53.79	55.63	54.66	.0	do.	9	3.8	1.6
510	do.	206.0	210	98.1	6.99	8.46	8.92	10.06	10.33	62.40	64.08	61.97	.0	do.	11	4.7	1.3
401	Rhode Island No. 1	117.1	210	55.8	4.19	4.81	4.93	7.05	7.70	48.63	53.11	40.91	.0	Spreading	5	9.0	.7
344	Tennessee No. 1	217.7	210	103.7	7.05	8.47	8.90	10.07	10.31	65.01	66.56	65.08	......	Alternate	7	4.4	1.7
345	do.	234.6	210	111.7	7.00	8.42	8.77	10.25	10.28	66.22	66.09	64.13	14.0	do.	7	4.3	1.8
346	do.	229.9	210	109.5	7.02	8.43	8.80	9.92	10.53	64.02	67.96	66.53	16.5	do.	8	4.2	1.8
411	do.	282.8	210	134.7	8.44	9.83	10.03	10.55	10.93	67.83	70.26	69.68	17.0	do.	5	3.6	1.5
409	do.	231.6	210	110.3	8.23	9.59	9.84	10.48	10.58	67.41	68.06	67.43	.0	do.	7	4.4	3.3
367	Tennessee No. 2	272.7	210	129.9	7.10	8.38	8.79	9.25	9.46	59.19	60.54	59.98	40.0	do.	9	3.1	1.4
368	do.	214.8	210	102.3	7.63	9.06	9.54	10.36	10.52	66.29	67.31	65.77	16.5	do.	5	4.6	3.3
369	do.	172.8	210	82.3	7.75	9.14	9.64	10.40	10.57	66.54	67.63	66.17	20.5	do.	......	6.8	5.0
349	Tennessee No. 3	220.6	210	105.0	6.81	8.18	8.65	9.10	9.49	58.99	61.51	60.58	39.0	do.	10	4.4	3.0
350	do.	239.5	210	114.0	7.31	8.82	9.43	10.01	10.35	64.97	67.18	66.52	21.5	do.	6	4.3	2.5
355	Tennessee No. 4	232.6	210	110.8	7.36	8.62	9.21	10.09	10.39	65.12	67.05	66.17	23.5	do.	6	4.0	1.8
356	do.	263.8	210	125.6	7.48	8.69	9.22	10.07	10.53	64.96	67.98	67.01	23.5	do.	8	3.8	1.7
405	do.	221.2	210	105.3	8.22	9.54	9.82	10.71	10.79	68.49	69.00	68.05	11.0	do.	6	4.1	2.0

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Horsepower.			Economic results (pounds of water evaporated per pound of fuel).					Efficiency (per cent) of—			Smoke (per cent of black).	Kind of firing.	Methods of firing.		
		Developed on test.	Builder's rating.	Per cent of rated horsepower developed.	Apparent under actual conditions as fired.	Equivalent from and at 212° F.				Boiler, from actual weight of ash.	Boiler, from analysis of ash and coal.	Boiler and grate.			Thickness of fire (inches).	Interval between.	
						As fired.	Dry.	Combustible determined from—								Normal firings (minutes).	Times of leveling or breaking up (hours).
								Actual weight of ash.	Analysis of ash and coal.								
1	2	72(65)	73(66)	74(67)	75(68)	76(69)	77(70)	78(71)	79(71.1)	80(72)	81(72.1)	82(73)	83(77)	84(80)	85(81)	86(82)	87(83)
352	Tennessee No. 5	200.3	210	95.4	7.08	8.52	9.02	9.98	10.31	63.52	65.62	64.08	0.0	Alternate	8	4.8	2.0
357	do	233.5	210	111.2	7.14	8.33	8.84	9.66	9.89	61.27	62.73	61.90	16.5	do	8	4.0	1.7
358	do	242.5	210	115.5	7.49	8.69	9.32	10.15	10.52	64.48	66.83	65.77	14.5	do	7	4.1	1.4
379	Tennessee No. 6	191.6	210	91.2	7.30	8.61	8.85	10.32	11.29	65.02	71.14	68.89	.0	do	8	3.9	1.1
381	do	169.5	210	80.7	6.42	7.61	7.86	9.33	10.04	58.81	63.28	60.70	.0	do	7	3.5	.7
372	Tennessee No. 7A	211.4	210	100.7	7.04	8.33	8.59	9.86	10.11	63.61	65.22	63.98	33.5	do	7	4.1	2.0
373	do	266.9	210	127.1	6.93	8.23	8.49	9.59	10.06	62.37	65.43	64.65	30.5	do	7	3.4	1.7
374	do	192.0	210	91.4	7.22	8.56	8.86	10.18	10.48	65.68	67.62	66.50	20.0	do	6	5.0	1.4
406	Tennessee No. 7B	226.9	210	108.0	7.66	8.92	9.28	9.98	10.42	63.74	66.55	65.80	....	do	6	4.2	2.1
384	Tennessee Nos. 8A and 8B	152.9	210	72.8	6.87	8.12	8.32	9.85	10.19	63.20	65.37	62.98	10.5	do	....	5.0	1.0
385	do	181.6	210	86.5	6.98	8.20	8.40	9.76	9.94	62.18	63.33	61.97	28.0	do	8	3.9	1.7
388	do	222.8	210	106.1	7.68	8.99	9.26	10.26	10.52	65.51	67.17	66.08	.0	do	8	3.9	1.3
363	Tennessee No. 9A	206.9	210	98.5	7.21	8.50	8.89	10.31	10.47	65.30	66.31	64.76	10.0	do	7	3.6	1.0
364	do	224.4	210	106.9	7.20	8.41	8.71	9.93	10.15	62.75	64.14	63.09	23.0	do	10	3.2	1.0
365	do	207.4	210	98.8	6.92	8.10	8.40	9.81	10.16	62.03	64.24	62.70	12.0	do	8	3.5	1.1
398	Tennessee No. 9B	239.5	210	114.0	7.71	9.03	9.43	10.32	10.62	65.67	67.58	66.90	.0	do	12	4.0	1.3
407	Tennessee No. 10	165.0	210	78.6	6.53	7.58	7.77	9.14	9.42	59.08	60.89	59.24	.0	do	8	4.6	.9
408	do	195.6	210	93.1	7.21	8.38	8.63	10.31	10.83	67.15	70.54	67.91	.0	do	6	4.4	1.3
22	Texas No. 1	57.3	210	27.3	3.08	3.60	4.69	6.25	6.70	43.98	47.15	41.61	2.0	Spreading	10	11.0	.5
291	Texas No. 4	187.1	210	89.1	3.68	4.40	6.90	7.85	8.09	59.55	61.37	59.86	.0	do	5	6.0	2.5
298	do	218.6	210	104.1	3.11	3.75	5.88	6.36	6.86	48.22	52.01	51.16	12.0	do	12	5.4	1.9
308	do	202.4	210	96.4	3.81	4.60	5.62	6.54	6.99	49.63	53.05	49.00	14.0	do	10	7.2	1.1
402	Utah No. 2	168.8	210	80.4	4.43	5.12	5.78	6.87	7.28	49.10	51.67	44.18	.0	do	8	5.3	3.1
403	do	152.1	210	72.4	6.19	7.21	7.95	8.74	9.22	61.66	65.04	60.02	8.5	do	6	7.9	1.4
404	do	145.4	210	69.2	5.64	6.48	7.20	8.37	8.56	59.41	60.75	55.24	.0	do	8	5.6	2.0
281	Virginia No. 1	193.7	210	92.2	7.95	9.54	10.01	10.69	10.78	68.04	68.61	67.69	....	Alternate	8	5.0	1.4

282	do.	193.8	210	92.3	7.82	9.39	9.89	10.48	10.72	66.72	68.25	67.27	16.4	do.	5	5.0	1.6
247	Virginia No. 2.	218.3	210	104.0	8.21	9.76	10.02	10.54	10.74	66.58	67.85	67.00	42.0	do.	8	4.4	4.0
251	do.	200.8	210	95.6	7.82	9.32	9.65	10.17	10.45	64.14	65.91	65.24	44.4	do.	8	4.5	2.0
256	do.	184.0	210	87.6	7.67	9.16	9.56	10.18	7.45	64.28	65.93	64.48	32.8	do.	12	4.7	1.4
260	do.	184.1	210	87.7	7.79	9.36	9.68	10.34	10.38	65.69	65.94	64.48	40.8	do.	10	5.1	1.2
280	Virginia No. 3.	171.4	210	81.6	8.14	9.74	9.91	10.79	10.66	66.58	65.77	64.19	......	do.	8	5.4	2.5
283	do.	175.9	210	83.8	8.18	9.79	10.12	10.73	10.84	66.14	66.82	65.43	17.0	do.	......	5.4	1.3
240	Virginia No. 4.	178.8	210	85.1	7.83	9.38	9.66	10.13	10.39	63.91	65.55	64.08	44.2	do.	12	5.1	2.4
248	do.	204.9	210	97.5	8.23	9.81	10.18	......	10.86	......	68.52	66.98	14.0	do.	7	4.7	4.0
254	do.	203.4	210	96.9	7.76	9.22	9.62	......	10.20	......	65.77	64.45	33.0	do.	12	4.3	2.5
476	Virginia No. 5A.	209.4	210	99.7	6.20	7.46	7.83	10.58	10.77	65.96	67.13	60.63	1.5	do.	12	3.4	.8
482	do.	310.1	210	147.7	5.89	7.13	7.47	9.27	9.67	57.74	60.28	56.90	20.5	Spreading.	9	3.8	1.3
494	Virginia No. 5B.	210.8	210	100.4	7.02	8.48	8.93	10.91	11.05	67.65	68.52	65.72	.0	Alternate.	7	4.3	.8
507	Virginia No. 6.	213.7	210	101.8	7.01	8.49	8.88	10.11	10.30	62.22	63.39	60.15	3.0	do.	9	3.9	.6
290	Washington No. 1B.	171.7	210	81.8	5.22	6.25	7.44	9.02	9.26	63.36	65.04	61.08	10.0	do.	5	4.5	1.7
359	Washington No. 2.	204.6	210	97.4	7.13	8.50	8.78	10.10	10.27	65.55	66.65	65.24	33.5	do.	10	3.8	1.7
360	do.	227.7	210	108.4	6.98	8.23	8.54	9.71	9.86	63.01	63.98	63.15	17.0	do.	7	3.5	1.3
361	do.	225.0	210	107.1	7.06	8.42	8.73	9.99	10.07	64.81	65.33	64.38	15.5	do.	6	3.5	1.3
412	do.	208.6	210	99.3	7.40	8.74	8.98	10.10	10.22	65.28	66.06	65.48	.0	do.	6	5.1	2.4
24	West Virginia No. 1.	199.2	210	94.8	7.44	8.78	8.95	9.70	9.90	61.12	62.38	60.87	50.6	do.	10	5.4	.7
25	West Virginia No. 2.	212.4	210	101.1	7.59	8.96	9.14	10.15	10.54	63.71	66.16	63.87	51.2	do.	8	4.9	.4
28	West Virginia No. 3.	211.6	210	100.7	7.40	8.85	9.08	10.34	10.59	64.61	66.18	63.90	14.0	do.	8	5.0	.4
31	West Virginia No. 4.	215.1	210	102.4	7.98	9.40	9.65	10.79	11.12	66.79	68.83	66.55	34.4	do.	10	5.0	.3
34	West Virginia No. 5.	207.8	210	99.0	7.92	9.39	9.59	10.74	11.05	66.94	68.91	66.85	19.0	do.	9	5.6	.4
39	West Virginia No. 6.	213.2	210	101.5	8.29	9.88	10.09	10.86	11.02	66.20	67.18	65.14	23.0	do.	11	5.6	.4
43	do.	208.5	210	99.3	8.46	10.08	10.30	11.07	11.91	67.46	68.31	66.17	22.6	do.	13	6.7	.5
51	West Virginia No. 7.	210.1	210	100.0	8.05	9.58	9.85	10.74	11.18	65.94	68.64	66.49	20.4	do.	14	6.1	.4
53	West Virginia No. 8.	211.6	210	100.7	7.62	9.11	9.62	10.68	10.64	66.27	66.02	64.85	46.2	do.	10-12	6.0	.5
60	West Virginia No. 9.	210.8	210	100.4	8.13	9.74	10.09	10.96	10.98	67.92	68.04	66.66	28.2	do.	9	6.4	.6
54	West Virginia No. 10.	205.9	210	98.1	7.94	9.48	9.65	10.58	10.72	63.76	64.60	62.06	28.0	do.	12	5.8	.3
56	West Virginia No. 11.	213.7	210	101.8	7.96	9.54	10.08	11.65	11.75	70.61	71.21	68.31	6.2	do.	12	5.9	.3
46	West Virginia No. 12.	206.1	210	98.1	8.17	9.74	9.90	10.76	10.82	65.13	65.50	63.02	23.6	do.	12	8.3	.5
59	do.	211.8	210	100.9	8.33	9.97	10.20	11.38	11.31	67.56	67.15	64.65	45.4	do.	13	......	.2
179	West Virginia No. 13.	208.2	210	98.8	8.71	10.12	10.50	10.98	11.11	67.57	68.68	67.60	24.0	do.	10	5.0	1.3
180	do.	189.3	210	90.1	8.69	10.11	10.59	11.07	11.29	68.40	69.76	68.48	21.0	do.	10	5.1	.8
178	West Virginia No. 14.	177.7	210	84.6	8.80	10.22	10.52	10.71	10.88	67.15	68.21	67.51	20.0	do.	12	6.0	1.1
181	do.	218.0	210	103.8	7.84	9.11	9.60	......	10.14	......	63.63	61.79	20.6	do.	10	4.5	.6
214	West Virginia No. 15.	158.0	210	75.2	7.65	9.00	9.18	10.95	10.92	68.73	68.54	63.76	32.8	do.	9	5.5	1.1
215	do.	177.2	210	84.4	7.44	8.77	8.99	9.88	10.04	61.59	62.91	61.13	46.2	do.	8	5.0	1.6
216	do.	216.2	210	103.0	7.14	8.41	8.65	9.34	9.63	58.48	60.30	58.84	54.6	do.	8	5.0	1.5
304	West Virginia No. 16A.	226.9	210	108.0	8.18	9.88	10.30	11.30	11.56	71.98	73.64	71.58	19.0	do.	10	4.0	2.7
305	do.	196.2	210	93.4	7.89	9.50	10.20	11.02	11.29	69.76	71.47	70.54	......	do.	10	4.7	1.1
225	West Virginia No. 17.	176.6	210	84.1	8.30	9.79	10.22	11.38	11.32	69.64	69.58	67.85	17.7	do.	10	5.1	.9
226	do.	184.0	210	87.6	8.06	9.53	9.94	11.03	11.04	67.75	67.81	66.16	7.8	do.	9	5.0	1.0
230	do.	186.9	210	89.0	8.08	9.61	10.05	10.98	11.01	67.75	67.94	66.29	23.8	do.	12	4.8	.8
261	West Virginia No. 18.	196.9	210	93.8	8.46	10.17	10.49	11.30	11.41	70.61	71.30	70.28	27.6	do.	10	4.9	2.5
262	do.	221.7	210	105.6	8.31	10.00	10.29	10.96	11.19	68.50	69.98	69.06	20.5	do.	8	4.3	1.7
285	West Virginia No. 19.	171.7	210	81.8	8.53	10.20	10.45	11.08	11.48	68.29	70.76	69.04	.0	do.	14	5.0	1.0
289	do.	167.2	210	79.6	8.25	9.94	10.26	11.38	11.45	70.22	70.65	68.00	.0	do.	10	5.4	.7
331	do.	242.0	210	115.2	7.29	8.78	9.19	10.10	9.99	61.80	61.13	60.00	.0	do.	12	4.6	.7
272	West Virginia No. 20.	164.8	210	78.5	8.24	9.49	10.11	11.19	11.21	69.92	70.05	68.75	17.4	do.	9	5.6	1.7
273	do.	175.5	210	83.6	8.13	9.75	10.04	10.92	11.19	68.38	70.07	68.85	12.2	do.	6	5.2	1.6
264	do.	190.1	210	90.5	8.41	10.09	10.46	11.21	11.21	70.23	70.23	69.26	26.0	do.	6	5.4	1.1

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Horsepower.			Economic results (pounds of water evaporated per pound of fuel).					Efficiency (per cent) of—			Smoke (per cent of black).	Kind of firing.	Methods of firing.		
		Developed on test.	Builder's rating.	Per cent of rated horsepower developed.	Apparent under actual conditions as fired.	Equivalent from and at 212° F.				Boiler, from actual weight of ash.	Boiler, from analysis of ash and coal.	Boiler and grate.			Thickness of fire (inches)	Interval between.	
						As fired.	Dry.	Combustible determined from—								Normal firings (minutes).	Times of leveling or breaking up (hours).
								Actual weight of ash.	Analysis of ash and coal.								
1	2	72(65)	73(66)	74(67)	75(68)	76(69)	77(70)	78(71)	79(71.1)	80(72)	81(72.1)	82(73)	83(77)	84(80)	85(81)	86(82)	87(83)
266	West Virginia No. 20	182.1	210	86.7	7.97	9.54	9.85	10.46	10.56	65.55	66.18	65.47	21.8	Alternate	8	5.2	1.4
274	West Virginia No. 21	234.9	210	111.9	8.27	9.94	10.31	10.90	10.87	68.96	68.77	68.53	....	do	6	4.3	1.8
275	do	197.7	210	94.1	8.23	9.80	10.20	10.98	11.05	69.53	69.97	68.92	....	do	6	....	1.5
296	do	213.8	210	101.8	8.11	9.69	10.03	10.81	10.96	68.50	69.45	67.86	13.5	do	12	4.5	1.4
267	do	200.4	210	95.4	8.06	9.67	10.10	10.62	10.64	66.68	66.81	65.94	36.0	do	12	4.8	3.3
446	West Virginia No. 22A	181.5	210	86.4	6.58	7.71	8.16	9.75	10.00	62.79	64.40	61.38	7.0	do	6	3.8	.7
447	do	208.1	210	99.1	7.06	8.28	8.76	10.08	10.61	64.66	68.40	65.87	13.0	do	10	3.9	.6
454	do	231.6	210	110.3	7.42	8.90	9.39	10.24	10.33	65.38	65.95	64.08	20.0	do	5	4.0	.7
438	West Virginia No. 22B	247.0	210	117.6	7.89	9.24	9.57	10.41	10.60	66.16	67.37	66.19	6.5	do	8	3.5	1.2
439	West Virginia No. 23A	209.4	210	99.7	7.49	8.73	8.92	10.08	10.20	63.80	64.56	61.55	13.0	do	7	3.8	.8
440	do	200.8	210	95.6	7.63	8.84	9.08	10.33	10.49	65.49	66.50	63.62	12.5	do	6	4.0	.7
444	West Virginia No. 23B	184.8	210	88.0	7.37	8.61	8.98	10.01	9.92	63.41	62.84	59.88	8.5	do	5	4.1	.7
445	do	201.4	210	95.9	7.47	8.75	8.97	10.36	10.65	66.08	67.93	64.17	27.0	do	5	4.2	.7
63	Wyoming No. 1	186.6	210	88.8	4.58	5.47	7.00	7.66	8.03	55.44	58.12	54.89	21.6	Spreading	8	7.3	.9
61	Wyoming No. 2	184.3	210	87.8	4.41	5.26	5.92	8.26	7.89	57.75	55.16	52.46	42.6	do	11	6.1	.6
196	Wyoming No. 2B	166.6	210	79.3	4.83	5.66	6.27	8.49	8.54	57.86	58.20	55.51	9.6	Alternate	8	4.8	1.0
210	do	185.4	210	88.3	5.30	6.19	6.84	9.26	9.01	62.75	61.06	58.66	.0	do	8	3.9	1.7
213	do	209.7	210	99.9	4.72	5.56	6.10	7.99	8.30	54.86	56.98	54.79	42.0	Spreading	8	4.8	1.7
211	Wyoming No. 3	140.8	210	67.0	5.12	5.98	7.04	8.46	9.17	62.39	67.62	64.63	.0	Alternate	8	4.5	2.0
212	do	185.2	210	88.2	4.95	5.81	6.73	8.01	8.59	59.75	64.08	61.80	22.7	Spreading	8	5.8	1.6
223	do	170.2	210	81.0	5.54	6.53	8.07	9.02	9.05	63.13	63.34	61.65	21.0	Alternate	6	4.7	2.2
399	Wyoming No. 4	199.9	210	95.2	5.32	6.22	7.10	8.06	8.18	58.76	59.63	56.10	19.0	Spreading	5	5.6	1.1
400	Wyoming No. 6	195.6	210	93.1	4.76	5.56	6.82	7.66	7.92	55.94	57.84	52.74	3.5	do	5	5.2	2.5
419	do	116.9	210	55.7	5.13	5.97	7.07	8.29	8.44	59.43	60.51	52.43	.0	do	12,5	3.1	1.3

	MISCELLANEOUS.																
451	Argentine Republic No. 1	71.8	210	34.2	1.96	2.34	2.51	4.88	6.80	36.61	51.06	40.85	.0	Alternate	10	5.6	.7
458	do	111.1	210	52.9	3.04	3.66	4.38	6.98	7.95	50.76	57.82	50.97	.0	Spreading	8	4.3	.5
485	do	156.1	210	74.3	3.20	3.87	4.24	7.22	8.52	51.21	60.44	49.72	4.0	Alternate	12	4.8	.6
172	Brazil No. 1	154.1	210	73.4	4.48	5.16	5.80	7.55	8.43	52.68	58.83	55.85	.0	Spreading	7	6.8	1.3
173	do	178.4	210	85.0	4.67	5.43	6.09	8.11	8.94	57.49	63.38	59.82	.0	do		6.3	1.9
	Mixed coals (accurately sized):																
348	1½ to 3 inches	208.1	210	99.1	5.15	6.22	7.43	8.69	8.63	58.84	58.43	57.05	26.5	Alternate	10	3.6	1.9
347	1 to 1½ inches	204.3	210	97.3	5.12	6.18	7.39	8.70	8.81	58.69	59.43	58.06	30.0	do	5	4.0	1.1
351	¾ to 1 inch	173.1	210	82.4	5.28	6.29	7.59	8.90	9.05	60.47	61.49	60.24	26.5	do	6	4.4	2.7
362	½ to ¾ inch	183.2	210	87.2	5.45	6.43	7.71	8.66	9.26	59.89	64.04	63.00	.0	do	5	3.7	1.8
366	⅜ to ½ inch	197.0	210	93.8	5.02	5.78	7.12	8.24	8.59	55.94	58.32	57.05	36.5	Spreading	8	4.2	1.4
370	¼ to ⅜ inch	185.9	210	88.5	4.98	5.87	7.02	8.51	8.69	58.52	59.75	58.33	21.0	Alternate	5	3.6	1.1
371	Under ¼ inch	135.6	210	64.6	4.44	5.21	6.31	7.93	8.54	55.00	59.23	55.44	.0	Spreading	5	4.4	.7
	Mixed coals:																
245	Pennsylvania No. 8 dried and Virginia No. 4.	179.9	210	85.7	7.27	8.66	8.93	9.56	9.81	60.13	61.70	59.57	22.8	Alternate	8	5.5	.8
414	Utah No. 1 and Rhode Island No. 1.	174.3	210	83.0	6.75	7.86	8.05	9.18	9.35	61.42	62.55	60.52	.0	do	7	5.3	1.3
415	do	191.2	210	91.0	7.17	8.36	8.55	9.75	9.89	65.73	66.68	64.39	.0	do	9	4.7	1.7
416	Utah No. 2 and Rhode Island No. 1.	163.7	210	78.0	4.26	4.95	5.26	7.19	7.70	51.05	54.68	41.49	.0	Spreading	6	5.3	2.0
	Special tests:																
500	Illinois	235.5	210	112.1	5.75	6.98	7.99	9.06	9.10	62.26	62.53	61.31	19.7	Alternate	2	3.4	1.8
501	do	194.6	210	92.7	5.34	6.49	7.47	8.50	8.52	57.43	57.56	56.26	32.0	Spreading	3	9.3	1.1
502	do	199.6	210	95.0	5.50	6.67	7.76	8.87	8.93	60.08	60.49	59.24	15.0	Coking		7.4	2.2
503	do	224.0	210	106.7	5.51	6.69	7.78	9.04	9.18	61.27	62.22	60.42	2.5	Ribbon	2	2.3	1.4
504	do	211.6	210	100.8	5.49	6.64	7.45	8.44	8.46	57.07	57.21	56.48	12.0	Alternate	3	3.6	1.6
505	do	276.3	210	131.6	5.52	6.69	7.74	8.87	8.90	60.00	60.20	58.99	14.9	do	3	3.4	2.4
517	do	135.7	210	64.6	5.82	7.06	8.02	10.07	9.41	67.81	63.36	60.22	23.0	Spreading	8	6.2	2.1
479	Washery refuse	152.5	210	72.6	2.63	3.17	3.56	7.43	8.06	52.61	57.08	47.48	.0	do	16	2.8	.6
519	Mixed coke	273.7	210	130.3	6.44	7.80	8.35	9.55	10.00	64.32	67.35	65.21	.0	do	5	5.4	3.0

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Analysis of the dry gases (per cent). Carbon dioxide (CO_2).	Analysis of the dry gases (per cent). Oxygen (O_2).	Analysis of the dry gases (per cent). Carbon monoxide (CO).	Analysis of the dry gases (per cent). Nitrogen (by difference) (N_2).	Pounds of dry gases per pound of combustible.	Heat balance. British thermal units. Total.	Heat balance. British thermal units. Absorbed by boiler.	Heat balance. British thermal units. Loss of heat due to— Moisture. In fuel.	Heat balance. British thermal units. Loss of heat due to— Moisture. Of burning hydrogen.	Heat balance. British thermal units. Loss of heat due to— Carried away in dry gases.	Heat balance. British thermal units. Loss of heat due to— Incomplete combustion of carbon.	Heat balance. British thermal units. Loss of heat due to— Radiation and other losses.	Heat balance. Per cent. Absorbed by boiler.	Heat balance. Per cent. Loss of heat due to— Moisture. In fuel.	Heat balance. Per cent. Loss of heat due to— Moisture. Of burning hydrogen.	Heat balance. Per cent. Loss of heat due to— Carried away in dry gases.	Heat balance. Per cent. Loss of heat due to— Incomplete combustion of carbon.	Heat balance. Per cent. Loss of heat due to— Radiation and other losses.
1	2	88 (84)	89 (85)	90 (86)	91 (88)	92	93	94	95	96	97	98	99	100	101	102	103	104	105
17	Ala. No. 1	8.30	11.43	0.00	80.27	25.13	15,094	10,005	40	654	3,380	0	1,015	66.28	0.27	4.34	22.42	0.00	6.69
21	do	8.30	11.70	.10	79.90	24.90	15,194	10,159	40	626	2,884	102	1,383	66.86	.26	4.12	18.98	.67	9.11
16	Ala. No. 2	8.20	11.70	.00	80.10	24.64	14,638	9,869	77	617	3,282	0	793	67.42	.53	4.21	22.43	.00	5.41
382	Ala. No. 2B	9.89	8.80	.15	81.16	20.18	14,462	9,464	58	579	2,267	123	1,971	65.44	.40	4.00	15.68	.85	13.63
383	do	7.35	12.29	.02	80.34	27.27	14,466	9,580	60	564	2,618	0	1,644	66.22	.42	3.90	18.10	.00	11.36
410	do	7.56	11.86	.02	80.56	27.06	14,765	10,265	53	639	3,584	0	224	69.52	.36	4.33	24.27	.00	1.52
390	Ala. No. 3	8.89	8.45	.23	82.43	22.94	15,024	10,130	50	606	3,210	216	812	67.43	.33	4.03	21.37	1.44	5.40
394	do	8.35	11.30	.09	80.26	24.81	15,025	9,860	48	607	3,465	91	954	65.62	.32	4.04	23.06	.61	6.35
375	Ala. No. 4	9.36	9.79	.05	80.80	22.63	15,347	10,188	61	649	2,873	46	1,530	66.38	.40	4.23	18.72	.30	9.97
376	do	8.18	11.32	.08	80.42	25.68	15,346	10,101	75	635	2,903	84	1,548	65.82	.49	4.14	18.92	.55	10.08
377	do	7.14	12.20	.02	80.64	29.52	15,361	10,439	95	640	3,457	0	730	67.96	.62	4.17	22.50	.00	4.75
378	do	7.73	11.91	.00	80.36	27.52	15,395	10,101	80	624	2,761	0	1,829	65.61	.52	4.05	17.93	.00	11.85
413	do	8.05	10.95	.07	80.93	25.78	15,300	9,937	38	634	4,213	74	404	64.95	.25	4.14	27.54	.48	2.64
478	Ala. No. 5	7.58	12.17	.11	80.14	27.14	15,115	9,985	98	621	3,869	122	420	66.06	.65	4.11	25.60	.80	2.78
480	do	8.89	10.25	.31	80.55	22.94	15,187	10,285	100	626	3,276	290	610	67.72	.66	4.12	21.57	1.91	4.02
484	Ala. No. 6	10.78	8.52	.19	80.51	19.87	15,634	10,613	43	623	2,966	153	1,236	67.88	.28	3.98	18.97	.98	7.91
9	Ark. No. 1	8.00	12.30	.08	79.62	27.05	15,654	10,352	30	524	3,468	89	1,191	66.13	.19	3.34	22.15	.57	7.62
14	do	9.39	10.57	.00	80.04	23.62	15,426	10,386	14	506	3,046	0	1,474	67.33	.09	3.28	19.75	.00	9.55
8	Ark. No. 2	7.74	11.80	.06	80.40	28.24	15,570	10,594	15	511	3,283	69	1,098	68.04	.10	3.28	21.08	.44	7.06
11	do	8.44	11.82	.03	79.71	25.83	15,572	10,507	76	540	3,265	35	1,149	67.47	.49	3.46	20.97	.22	7.39
29	Ark. No. 3	8.90	11.17	.07	79.86	24.26	15,626	10,768	29	526	2,978	69	1,256	68.91	.18	3.37	19.06	.44	8.04
35	do	7.52	12.94	.00	79.54	29.28	15,566	10,198	43	497	3,765	0	1,063	65.51	.28	3.19	24.19	.00	6.83
40	Ark. No. 4	8.87	11.06	.05	80.00	25.22	15,595	10,999	57	450	2,996	51	1,042	70.53	.37	2.89	19.21	.33	6.67

42	.....do.	7.84	11.97	.00	80.19	28.31	15,906	10,603	47	507	2,947	0	1,804	66.65	.30	3.19	18.53	.00	11.33
41	Ark. No. 5.	8.29	11.62	.09	80.00	26.33	15,434	9,880	33	474	2,983	97	1,997	63.82	.21	3.07	19.33	.08	12.94
293	Ark. No. 7A.	8.34	11.54	.11	80.01	25.83	15,352	10,642	81	513	2,852	116	1,148	69.32	.53	3.34	18.57	.76	7.48
294	.....do.	8.00	11.78	.02	80.20	27.16	15,346	9,985	85	520	3,246	0	1,510	65.07	.55	3.30	21.15	.00	9.84
297	Ark. No. 8.	7.32	12.61	.08	80.04	30.02	15,372	10,130	51	462	3,811	0	918	65.90	.33	3.01	24.79	.00	5.97
308	.....do.	8.30	11.26	.03	80.41	26.74	15,449	10,449	91	471	3,440	0	998	67.64	.50	3.05	22.26	.00	6.46
309	.....do.	9.83	8.89	.57	80.71	21.53	15,441	9,715	91	475	2,940	500	1,720	62.92	.50	3.08	19.04	3.24	11.13
340	Ark. No. 10.	9.95	9.08	.34	80.63	17.29	12,180	7,339	1,086	617	2,473	239	426	60.25	3.92	5.07	20.30	1.96	3.50
75	Colo. No. 1.	6.64	13.76	.05	79.55	28.18	13,478	8,266	336	609	3,287	58	982	61.28	2.49	4.52	24.88	.48	6.92
336	Fla. No. 1.	9.30	7.50	.10	83.10	16.65	11,003	6,403	306	686	2,513	68	1,027	58.19	2.78	6.28	22.84	.62	9.34
481	Ga. No. 1.	10.38	8.88	.08	80.68	20.64	15,645	10,999	52	576	2,982	67	969	70.31	.33	3.68	19.06	.43	6.19
18	Ill. No. 1.	8.50	11.14	.04	80.32	22.41	14,252	8,710	164	625	2,635	37	2,081	61.12	1.15	4.38	18.40	.26	14.60
19	Ill. No. 2.	8.40	11.40	.00	80.20	23.11	14,150	8,904	167	657	2,641	0	1,790	62.88	1.18	4.64	18.65	.00	12.65
38	Ill. No. 3.	7.10	13.40	.04	79.46	28.34	14,712	9,444	141	616	3,913	47	551	64.20	.96	4.18	26.60	.32	3.74
48	Ill. No. 4.	6.52	13.80	.00	79.68	30.47	14,823	8,440	244	622	4,034	0	953	56.98	1.71	4.34	28.16	.00	6.86
50	.....do.	7.40	12.60	.07	79.93	26.65	14,319	8,334	215	618	3,313	77	1,762	58.20	1.50	4.32	23.14	.54	12.30
73	Ill. No. 6.	6.73	13.35	.04	79.88	27.73	13,992	8,884	242	645	3,798	46	377	63.50	1.73	4.61	27.14	.33	2.69
106	Ill. No. 6B.	5.58	13.76	.53	80.13	31.56	14,229	7,194	260	618	4,686	692	770	50.56	1.89	4.34	32.93	4.86	5.42
313	.....do.	7.00	12.54	.00	80.46	27.36	13,936	9,358	236	560	2,969	0	822	67.15	1.60	4.02	21.24	.00	5.90
314	.....do.	7.67	11.03	.21	81.09	24.44	14,175	7,928	242	636	3,490	211	1,668	55.93	1.71	4.48	24.62	1.49	11.77
122	Ill. No. 7C.	6.76	13.10	.17	79.97	27.27	13,944	8,662	196	580	2,219	191	2,096	62.12	1.40	4.16	15.91	1.37	15.04
129	.....do.	7.88	11.63	.43	80.06	23.36	14,255	8,855	290	632	2,804	412	1,272	62.12	1.96	4.44	19.67	2.89	8.92
142	Ill. No. 7D.	7.89	11.59	.17	80.35	23.73	14,251	8,988	175	610	2,489	165	1,879	62.68	1.23	4.28	17.46	1.16	13.19
143	.....do.	7.33	12.27	.14	80.26	25.36	14,108	8,952	179	605	2,690	146	1,536	63.45	1.27	4.29	19.07	1.03	10.89
146	.....do.	8.39	11.31	.12	80.18	22.22	14,107	9,464	179	596	2,202	109	1,557	67.09	1.27	4.23	15.61	.77	11.03
516	Ill. No. 7E.	8.81	10.00	.16	81.03	20.98	13,894	7,928	314	642	3,449	137	1,424	57.06	2.26	4.62	24.82	.99	10.25
101	Ill. No. 8.	7.22	11.36	.74	80.68	23.65	14,113	7,484	229	616	,833	720	2,231	53.03	1.62	4.36	20.07	5.10	15.82
102	.....do.	7.47	11.41	.69	80.43	23.27	14,120	7,436	230	656	3,543	659	1,596	52.66	1.63	4.65	25.09	4.67	11.30
103	Ill. No. 9A.	7.38	11.61	.48	80.53	24.40	14,187	7,600	216	655	3,263	481	1,972	53.57	1.52	4.62	23.00	3.39	13.90
104	.....do.	8.33	9.97	.86	80.84	20.95	14,297	7,368	204	646	2,609	738	2,732	51.54	1.43	4.51	18.25	5.16	19.11
105	.....do.	5.69	13.88	.29	80.14	31.80	14,278	7,522	211	674	4,981	381	509	52.68	1.48	4.72	34.89	2.67	3.56
113	.....do.	8.85	9.71	.98	80.46	19.80	14,184	7,243	240	646	2,405	793	2,857	51.06	1.69	4.55	16.96	5.59	20.15
121	Ill. No. 9B.	9.58	9.03	1.01	80.38	18.24	14,303	8,527	169	611	1,769	751	2,476	59.62	1.18	4.27	12.37	5.25	17.31
492	Ill. No. 9C.	9.04	10.34	.06	80.56	21.43	14,371	9,049	272	620	3,106	52	1,272	62.97	1.89	4.32	21.61	.36	8.85
107	Ill. No. 10.	6.53	13.60	.25	79.62	29.40	14,545	8,855	204	641	4,309	302	234	60.88	1.40	4.41	29.63	2.08	1.60
108	.....do.	8.40	10.59	.99	80.02	21.33	14,550	7,996	154	634	2,938	864	1,964	54.96	1.06	4.35	20.19	5.94	13.51
109	.....do.	5.60	14.63	.03	79.74	35.20	14,546	9,193	167	595	3,413	44	1,134	63.20	1.15	4.09	23.46	.30	7.80
110	.....do.	6.33	13.08	1.09	79.55	26.81	14,541	7,774	138	579	2,162	1,205	2,683	53.46	.95	3.98	14.87	8.29	18.45
114	.....do.	9.80	9.48	.66	80.06	19.32	14,457	8,633	181	621	2,360	519	2,233	59.35	1.24	4.27	16.23	3.57	15.35
137	Ill. No. 11A.	9.52	10.07	.35	80.06	20.49	14,293	9,840	123	584	2,159	292	1,295	68.84	.86	4.09	15.11	2.04	9.06
138	.....do.	8.91	10.91	.33	79.85	21.88	14,320	9,782	122	586	2,368	295	1,167	68.31	.85	4.09	16.54	2.06	8.15
139	.....do.	8.65	10.89	.33	80.13	22.37	14,269	10,063	116	569	2,115	301	1,105	70.52	.81	3.99	14.82	2.11	7.75
141	.....do.	8.42	11.37	.18	80.03	23.50	14,336	9,367	119	588	2.606	173	1,483	65.34	.83	4.10	18.18	1.20	10.35
111	Ill. No. 11B.	7.64	11.59	.53	80.24	24.60	14,559	7,928	127	587	2,610	535	2,772	54.46	.87	4.03	17.93	3.67	19.04
112	.....do.	8.87	10.29	.47	80.37	21.56	14,738	8,682	141	602	2,328	414	2,571	58.91	.95	4.08	15.80	2.81	17.45
115	.....do.	9.08	10.44	.48	80.00	21.09	14,738	8,884	146	606	2,354	413	2,335	60.28	.99	4.11	15.97	2.80	15.85
116	.....do.	9.36	9.76	.86	80.02	19.73	14,728	8,489	112	602	2,159	691	2,675	57.64	.76	4.09	14.66	4.69	18.16
117	.....do.	8.21	11.12	.65	80.02	22.55	14,524	8,218	105	596	2,674	600	2,331	56.58	.72	4.10	18.41	4.13	16.06
118	.....do.	10.73	7.92	.76	80.59	17.64	14,628	8,172	94	591	1,956	544	3,271	55.87	.64	4.04	13.37	3.72	22.36
119	.....do.	10.20	8.88	.83	80.09	18.42	14,780	8,170	99	621	2,303	621	2,966	55.28	.67	4.20	15.58	4.20	20.07
120	Ill. No. 11C.	10.44	7.99	1.60	79.97	16.89	14,572	8,440	134	580	1,613	1,097	2,708	57.92	.92	3.98	11.07	7.53	18.58
312	.....do.	9.43	9.72	.00	80.85	21.66	14,647	9,498	150	603	2,582	0	1,869	64.81	1.02	4.12	17.29	.00	12.76

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Analysis of the dry gases (per cent).				Pounds of dry gases per pound of combustible.	Heat balance.												
							British thermal units.							Per cent.					
									Loss of heat due to—						Loss of heat due to—				
									Moisture.						Moisture.				
		Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Nitrogen (by difference) (N_2).		Total.	Absorbed by boiler.	In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.	Absorbed by boiler.	In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.
1	2	88 (84)	89 (85)	90 (86)	91 (88)	92	93	94	95	96	97	98	99	100	101	102	103	104	105
127	Ill. No. 12	8.86	10.62	0.52	80.00	20.40	14,349	9,271	143	610	2,673	443	1,209	64.61	1.00	4.25	18.62	3.09	8.43
128	....do	10.13	9.19	.45	80.23	18.60	14,341	9,503	128	597	2,187	340	1,586	66.26	.90	4.16	15.25	2.37	11.06
131	....do	9.11	10.30	.34	80.25	20.60	14,413	9,840	165	596	2,457	286	1,069	68.28	1.14	4.14	17.05	1.98	7.41
133	....do	9.22	10.26	.21	80.31	20.71	14,296	9,396	144	581	2,142	177	1,856	65.73	1.00	4.07	14.98	1.24	12.98
135	....do	9.14	10.27	.34	80.25	21.08	14,607	9,647	160	612	2,428	292	1,468	66.05	1.10	4.19	16.62	2.00	10.04
136	....do	8.31	11.45	.37	79.87	22.58	14,363	9,541	175	594	2,417	342	1,294	66.43	1.22	4.13	16.83	2.38	9.01
463	Ill. No. 12B	8.24	11.30	.24	80.22	23.73	14,479	9,502	113	606	3,343	233	682	65.63	.78	4.18	23.09	1.61	4.71
132	Ill. No. 13	10.66	8.55	.57	80.22	18.11	14,473	9,812	152	590	1,930	418	1,571	67.79	1.05	4.08	13.33	2.89	10.86
134	....do	9.85	9.75	.23	80.17	20.06	14,432	9,493	151	584	2,070	187	1,947	65.78	1.04	4.04	14.34	1.30	13.50
144	....do	11.24	7.93	.36	80.47	17.59	14,472	9,744	147	597	1,984	256	1,744	67.33	1.02	4.12	13.71	1.77	12.05
145	....do	11.27	7.83	.34	80.56	17.57	14,468	10,005	158	579	1,674	242	1,810	69.15	1.09	4.00	11.57	1.67	12.52
123	Ill. No. 14	9.24	9.75	.70	80.31	19.36	14,184	8,682	192	594	1,942	553	2,221	61.21	1.35	4.19	13.69	3.90	15.66
125	....do	8.75	10.64	.59	80.02	20.71	14,146	8,739	212	612	2,391	499	1,693	61.78	1.50	4.32	16.90	3.53	11.97
130	....do	10.18	8.54	.48	80.80	18.47	14,311	8,556	268	623	2,194	360	2,310	59.79	1.87	4.36	15.33	2.51	16.14
126	Ill. No. 15	8.57	10.97	.50	79.96	21.07	14,176	9,168	170	611	2,474	431	1,322	64.68	1.20	4.31	17.45	3.04	9.32
152	....do	9.31	10.06	.31	80.32	20.37	14,486	9,309	187	621	2,332	257	1,780	64.26	1.29	4.28	16.10	1.77	12.30
150	Ill. No. 16	9.86	9.64	.25	80.25	20.12	14,507	10,063	145	590	2,429	204	1,076	69.36	1.00	4.06	16.74	1.41	7.43
140	Ill. No. 18	8.29	11.23	.28	80.20	22.51	14,472	9,560	181	626	2,183	258	1,664	66.06	1.25	4.33	15.08	1.78	11.50
148	....do	8.26	11.42	.22	80.10	23.02	14,572	8,817	177	651	2,646	207	2,074	60.50	1.21	4.47	18.16	1.42	14.24
147	....do	10.24	9.10	.22	80.44	18.85	14,541	9,522	239	654	2,167	168	1,791	65.48	1.64	4.50	14.90	1.16	12.32
149	....do	9.04	10.49	.11	80.36	21.52	14,421	9,734	270	655	2,464	97	1,201	67.50	1.87	4.54	17.08	.67	8.34
160	Ill. No. 19A	12.71	6.36	.31	80.62	15.99	14,306	9,126	205	562	1,880	190	2,424	63.40	1.42	3.91	13.06	1.38	16.83
161	....do	10.22	9.51	.13	80.14	19.92	14,385	9,821	213	548	2,022	105	1,676	68.27	1.48	3.81	14.06	.73	11.65

163	.....do..........	10.32	9.27	.12	80.29	19.75	14,397	9,367	207	568	2,882	96	1,277	65.06	1.44	3.95	20.02	.67	8.86
170	.....do..........	9.67	9.97	.05	80.31	21.17	14,392	9,512	218	566	2,561	43	1,492	66.09	1.51	3.93	17.79	.30	10.38
171	.....do..........	10.42	8.97	.14	80.47	19.53	14,397	9,947	212	550	2,156	111	1,412	69.09	1.47	3.88	14.98	.77	9.81
175	Ill. No. 19B.......	11.54	7.28	.21	81.02	17.94	14,683	10,169	172	593	2,170	155	1,424	69.26	1.17	4.04	14.78	1.06	9.69
204	.....do..........	12.36	5.94	.18	81.52	16.83	14,660	10,459	152	598	2,084	122	1,245	71.34	1.04	4.08	14.22	.83	8.49
205	.....do..........	11.56	6.74	.10	81.60	18.06	14,675	10,458	168	602	2,293	73	1,081	71.27	1.14	4.10	15.62	.50	7.37
420	Ill. No. 19C.......	9.45	9.86	.04	80.65	21.57	14,384	9,657	140	613	2,583	35	1,336	67.23	.98	4.27	17.98	.24	9.30
423	.....do..........	8.85	10.45	.08	80.67	23.00	14,370	9,778	151	611	2,672	28	1,135	68.01	1.05	4.25	18.50	.20	7.90
424	Ill. No. 19D.......	9.45	10.14	.07	80.34	21.08	14,220	9,657	135	541	2,570	60	1,266	67.87	.95	3.80	18.06	.42	8.90
425	.....do..........	9.54	9.87	.13	80.46	20.76	14,220	9,744	135	580	2,536	110	1,164	68.48	.95	3.80	17.82	.77	8.18
421	Ill. No. 19E.......	9.26	10.46	.02	80.26	21.60	14,215	9,589	147	539	2,566	0	1,374	67.46	1.08	3.79	18.05	.00	9.67
422	.....do..........	10.17	9.26	.05	80.52	19.94	14,347	9,850	157	539	2,407	40	1,354	68.66	1.09	3.75	16.78	.28	9.44
292	Ill. No. 20.........	7.96	11.61	.02	80.41	23.74	13,953	9,280	266	604	2,832	0	971	66.51	1.91	4.83	20.29	.00	6.96
301	.....do..........	9.69	9.42	.16	80.73	19.71	14,204	9,107	301	639	2,800	128	1,319	63.71	2.10	4.47	19.59	.90	9.28
302	.....do..........	9.86	9.30	.11	80.73	19.50	14,303	9,242	300	645	2,911	87	1,118	64.61	2.10	4.51	20.35	.61	7.82
315	Ill. No. 21.........	8.56	10.77	.14	80.53	22.43	14,251	9,609	279	628	2,972	128	635	67.42	1.96	4.41	20.85	.90	4.46
316	.....do..........	8.90	10.61	.00	80.49	22.08	14,302	9,203	274	626	2,824	0	1,375	64.35	1.92	4.37	19.75	.00	9.61
318	.....do..........	10.38	8.84	.02	80.76	19.16	14,185	9,078	317	602	2,626	0	1,562	64.00	2.23	4.25	18.51	.00	11.01
324	Ill. No. 22A.......	9.63	9.36	.17	80.84	19.12	13,978	9,367	208	603	2,441	132	1,227	67.01	1.49	4.32	17.46	.94	8.78
325	.....do..........	9.37	9.56	.16	80.91	19.76	14,043	9,280	184	610	2,566	129	1,274	66.09	1.31	4.34	18.27	.92	9.07
328	.....do..........	10.28	8.46	.00	81.26	19.02	14,296	8,846	244	628	2,556	0	2,022	61.88	1.71	4.39	17.88	.00	14.14
306	Ill. No. 23A.......	9.36	9.50	.05	81.09	20.21	13,954	9,531	260	638	2,445	41	1,039	68.31	1.86	4.57	17.52	.29	7.45
317	.....do..........	8.86	10.26	.00	80.88	21.93	14,279	8,991	254	670	2,821	0	1,543	62.97	1.78	4.69	19.76	.00	10.80
321	Ill. No. 23B.......	9.82	8.98	.02	81.18	19.46	14,397	8,614	227	635	2,466	0	2,455	59.83	1.58	4.41	17.13	.00	17.05
322	.....do..........	9.90	8.77	.14	81.19	19.07	14,397	8,382	228	638	2,531	109	2,509	58.22	1.58	4.43	17.58	.76	17.43
335	Ill. No. 24B.......	9.32	9.94	.15	80.59	20.38	14,120	9,174	210	630	2,744	125	1,237	64.97	1.49	4.46	19.43	.89	8.76
336	.....do..........	8.96	10.15	.10	80.79	21.49	14,230	8,662	217	645	2,940	88	1,678	60.87	1.53	4.53	20.66	.62	11.79
337	.....do..........	10.00	9.19	.20	80.61	19.11	14,193	9,107	243	658	2,899	155	1,131	64.17	1.71	4.64	20.42	1.09	7.97
338	Ill. Nos. 25A and 25B...........	7.32	11.94	.00	80.74	26.17	14,439	8,382	218	684	3,831	0	1,324	58.05	1.51	4.74	26.53	.00	9.17
339	.....do..........	8.28	10.93	.03	80.76	22.70	14,242	8,875	208	669	3,378	0	1,112	62.32	1.46	4.69	23.72	.00	7.81
341	Ill. No. 26.........	8.89	10.16	.06	80.89	21.54	14,177	8,971	239	608	2,550	53	1,747	63.28	1.69	4.29	18.05	.37	12.32
342	.....do..........	9.12	10.03	.09	80.76	21.23	14,312	8,971	280	615	2,517	78	1,851	62.68	1.96	4.30	17.59	.54	12.93
353	Ill. No. 27.........	9.56	8.96	.19	81.29	19.60	14,150	9,319	289	613	2,187	152	1,590	65.86	2.04	4.33	15.46	1.07	11.24
354	.....do..........	7.43	11.51	.29	80.77	24.28	14,039	9,512	287	609	2,698	289	644	67.75	2.04	4.34	19.22	2.06	4.59
459	Ill. No. 28A.......	8.63	10.88	.12	80.37	23.48	14,447	9,454	119	572	3,139	115	1,048	65.44	.82	3.96	21.73	.80	7.25
457	Ill. No. 28B.......	8.87	10.31	.04	80.78	22.70	14,522	9,763	93	626	3,285	37	718	67.23	.64	4.31	22.62	.26	4.94
448	Ill. No. 28C.......	11.16	7.23	.09	81.52	18.25	14,532	9,647	75	606	2,584	67	1,553	66.38	.52	4.17	17.78	.46	10.69
452	.....do..........	10.63	8.64	.06	80.67	19.25	14,564	10,005	111	610	2,777	47	1,014	68.70	.76	4.19	19.07	.32	6.96
465	Ill. No. 29A.......	10.02	9.08	.05	80.85	19.59	14,318	9,551	245	635	2,962	40	885	66.71	1.71	4.43	20.69	.28	6.18
460	Ill. No. 29B.......	9.38	9.45	.11	81.06	19.93	14,188	9,541	197	631	2,798	89	932	67.25	1.39	4.45	19.72	.63	6.56
461	.....do..........	9.65	9.04	.06	81.25	19.84	14,372	9,251	213	646	2,805	48	1,409	64.37	1.48	4.50	19.52	.33	9.80
466	.....do..........	10.34	8.57	.04	81.05	18.97	14,476	9,686	169	660	2,768	31	1,162	66.91	1.17	4.56	19.12	.21	8.03
511	Ill. No. 30.........	9.01	9.98	.19	80.82	21.35	14,617	9,261	162	647	3,336	166	1,045	63.36	1.11	4.43	22.82	1.13	7.15
489	Ill. No. 31.........	10.05	9.16	.02	80.77	19.69	14,379	9,474	259	643	2,642	0	1,361	65.89	1.80	4.47	18.37	.00	9.47
491	.....do..........	9.02	10.14	.06	80.78	21.51	14,388	9,435	188	635	3,015	53	1,062	65.58	1.31	4.41	20.95	.37	7.38
513	Ill. No. 33.........	7.74	11.88	.17	80.21	25.11	14,486	8,237	230	594	3,863	175	1,387	56.86	1.59	4.10	26.67	1.21	9.57
509	Ill. No. 34B.......	9.97	9.31	.13	80.59	19.94	14,847	9,454	103	643	3,058	105	1,484	63.68	.69	4.33	20.60	.71	9.99
71	Ind. No. 1.........	8.70	11.02	.08	80.20	23.09	14,672	9,145	189	584	3,129	75	1,549	62.33	1.29	3.97	21.32	.51	10.58
68	.....do..........	8.98	10.43	.32	80.27	21.56	14,763	9,193	287	645	2,855	281	1,502	62.27	1.94	4.36	18.94	1.90	10.59
65	Ind. No. 2.........	7.65	11.98	.09	80.28	25.23	14,428	9,203	152	651	3,265	93	1,064	63.79	1.05	4.51	22.63	.63	7.38
162	Ind. No. 3.........	10.44	8.64	.31	80.61	17.83	14,095	9,802	215	619	2,033	224	1,202	69.54	1.53	4.39	14.42	1.59	8.53
151	Ind. No. 4.........	8.05	11.75	.19	80.01	23.92	14,356	9,241	250	600	2,704	186	1,375	64.37	1.74	4.18	18.84	1.30	9.57

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Analysis of the dry gases (per cent). Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Nitrogen (by difference) (N_2).	Pounds of dry gases per pound of combustible.	Heat balance. British thermal units. Total.	Absorbed by boiler.	Loss of heat due to— Moisture. In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.	Per cent. Absorbed by boiler.	Loss of heat due to— Moisture. In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.
1	2	88 (84)	89 (85)	90 (86)	91 (88)	92	93	94	95	96	97	98	99	100	101	102	103	104	105
165	Ind. No. 4	8.86	10.87	0.09	80.18	22.10	14,363	10,072	247	589	2,259	81	1,115	70.13	1.72	4.10	15.73	0.56	7.76
166	do	8.05	11.72	.28	79.95	23.64	14,345	9,522	264	591	2,474	271	1,223	66.38	1.84	4.12	17.24	1.89	8.53
154	do	9.92	9.35	.18	80.55	19.82	14,658	9,522	241	610	2,378	145	1,762	64.96	1.64	4.16	16.23	.99	12.02
153	Ind. No. 5	8.76	10.33	.23	80.68	21.55	14,351	9,280	184	607	2,492	202	1,586	64.67	1.28	4.23	17.37	1.41	11.04
155	do	8.67	10.69	.20	80.44	21.93	14,459	9,570	194	607	2,495	179	1,414	66.19	1.34	4.20	17.26	1.24	9.78
156	do	8.14	11.26	.29	80.31	22.16	14,517	9,164	179	616	2,735	275	1,548	63.13	1.23	4.24	18.84	1.89	10.67
157	Ind. No. 6	8.33	11.26	.22	80.19	23.00	14,585	9,387	175	637	2,799	216	1,371	64.36	1.20	4.37	19.19	1.48	9.40
159	do	12.20	5.97	.60	81.23	15.82	14,684	8,865	183	650	1,993	383	2,610	60.37	1.24	4.42	13.57	2.61	17.79
158	Ind. No. 7A	11.43	7.34	.49	80.74	16.88	14,660	9,486	134	637	1,894	334	2,175	64.71	.91	4.34	12.92	2.28	14.84
268	do	8.64	10.87	.07	80.42	22.84	14,673	9,696	176	658	3,086	65	992	66.08	1.20	4.48	21.03	.44	6.77
164	Ind. No. 7B	11.04	8.53	.08	80.35	17.83	14,496	8,826	170	621	1,977	58	2,844	60.89	1.17	4.28	13.64	.40	19.61
176	do	8.40	10.67	.04	80.89	23.17	14,474	9,000	151	627	2,747	38	1,911	62.18	1.04	4.33	18.98	.26	13.21
182	Ind. No. 8	9.57	8.67	.15	81.61	20.47	14,680	9,193	154	646	2,677	125	1,885	62.63	1.05	4.40	18.24	.85	12.83
183	do	9.31	9.08	.15	81.46	20.92	14,636	9,512	176	639	2,641	128	1,540	64.99	1.20	4.37	18.04	.87	10.53
185	do	10.05	8.64	.17	81.14	19.62	14,725	9,290	171	652	2,613	136	1,863	63.11	1.16	4.42	17.74	.92	12.65
184	do	10.73	7.52	.25	81.50	18.45	14,623	9,590	198	660	2,488	187	1,501	65.60	1.35	4.51	17.00	1.28	10.26
168	Ind. No. 9A	10.28	8.23	.12	81.37	18.92	14,363	9,821	203	620	2,171	92	1,457	68.38	1.41	4.32	15.11	.64	10.14
169	do	9.59	9.67	.20	80.54	20.17	14,414	9,831	211	628	2,420	164	1,160	68.20	1.46	4.36	16.79	1.14	8.05
174	Ind. No. 9B	8.99	9.96	.13	80.92	21.55	14,498	9,178	191	653	2,648	114	1,718	63.28	1.32	4.50	18.26	.79	11.85
334	Ind. Nos. 9A and 9B	10.07	8.79	.23	80.91	19.25	14,456	9,367	221	641	2,994	180	1,055	64.79	1.53	4.43	20.71	1.24	7.30
167	Ind. No. 10	9.82	9.19	.24	80.75	19.39	14,515	9,667	166	644	2,034	189	1,815	66.60	1.14	4.44	14.01	1.30	12.51
177	do	11.09	6.42	.53	81.96	17.04	14,620	8,585	170	670	2,147	366	2,682	58.72	1.16	4.59	14.69	2.50	18.34
283	Ind. No. 11	11.76	6.72	.17	81.35	17.14	14,746	9,636	198	616	2,443	118	1,733	65.35	1.34	4.18	16.57	.80	11.75
284	do	10.76	8.43	.00	80.81	18.92	14,733	9,714	183	613	2,593	0	1,630	65.94	1.24	4.16	17.60	.00	11.06

235	.....do..........	11.07	8.04	.00	80.80	18.48	14,775	9,057	201	617	2,564	0	1,736	65.36	1.36	4.18	17.35	.00	11.75
299	Ind. No. 12........	8.76	10.03	.10	81.11	21.95	14,450	9,445	231	642	2,950	90	1,092	65.36	1.60	4.44	20.42	.62	7.56
300	.....do..........	9.21	9.63	.08	81.08	20.88	14,410	9,676	224	646	2,932	68	864	67.15	1.55	4.48	20.35	.47	6.00
310	.....do..........	9.98	8.91	.14	80.97	19.61	14,601	9,937	195	595	1,450	112	2,312	68.06	1.34	4.07	9.93	.77	15.83
432	Ind. No. 13........	9.86	9.37	.06	80.71	20.04	14,508	9,879	216	633	2,405	49	1,326	68.09	1.40	4.36	16.58	.34	9.14
433	.....do..........	9.50	9.78	.18	80.54	20.58	14,543	9,367	233	641	2,524	151	1,627	64.41	1.60	4.41	17.35	1.04	11.19
430	Ind. No. 14........	9.00	9.72	.09	81.19	20.82	14,223	9,464	141	634	2,513	76	1,395	66.54	.99	4.46	17.67	.53	9.81
431	.....do..........	8.96	10.25	.05	80.74	20.91	14,171	10,063	169	627	2,484	43	785	71.01	1.19	4.43	17.53	.30	5.54
428	Ind. No. 15........	9.86	9.35	.13	80.66	20.26	14,580	9,377	222	632	2,942	107	1,300	64.31	1.52	4.34	20.18	.73	8.92
429	.....do..........	9.08	10.37	.09	80.51	22.13	14,584	9,396	211	616	2,900	81	1,380	64.43	1.45	4.22	19.88	.56	9.46
426	Ind. No. 16........	8.96	10.01	.09	80.94	21.35	14,319	9,493	148	621	2,629	78	1,350	66.30	1.03	4.34	18.36	.54	9.43
427	.....do..........	8.62	10.65	.09	80.64	22.27	14,370	9,387	167	623	2,726	82	1,385	65.32	1.16	4.34	18.97	.57	9.64
441	Ind. No. 17........	9.37	9.83	.11	80.69	20.71	14,342	9,203	157	616	2,893	91	1,382	64.17	1.09	4.30	20.17	.63	9.64
442	.....do..........	8.13	11.23	.15	80.49	23.54	14,320	9,029	205	611	3,169	145	1,161	63.05	1.43	4.27	22.13	1.01	8.11
435	Ind. No. 18B.......	10.84	8.14	.03	80.99	18.59	14,721	9,522	189	612	2,222	0	2,176	64.68	1.28	4.16	15.10	.00	14.78
436	.....do..........	11.45	7.64	.19	80.72	17.47	14,755	9,705	194	628	2,277	134	1,817	65.77	1.32	4.26	15.43	.91	12.31
464	Ind. No. 19........	8.95	10.29	.02	80.74	21.31	14,401	9,290	160	627	2,941	0	1,383	64.51	1.11	4.36	20.42	.00	9.60
10	Ind. T. No. 1......	8.53	11.33	.00	80.14	23.74	14,767	10,150	123	680	3,009	0	855	68.73	.83	4.27	20.88	.00	5.79
20	Ind. T. No. 2......	9.45	10.17	.31	80.07	21.04	14,929	9,309	54	626	2,332	265	2,343	62.36	.36	4.19	15.62	1.78	15.69
417	Ind. T. No. 2B.....	9.01	9.80	.08	81.11	22.71	15,061	10,266	42	624	2,752	74	1,313	68.10	.28	4.14	18.27	.49	8.72
418	.....do..........	9.31	9.83	.09	80.77	21.96	15,042	10,285	42	622	2,672	81	1,340	68.38	.23	4.13	17.76	.54	8.91
455	.....do..........	9.54	9.34	.34	80.78	21.05	15,217	9,193	40	643	2,981	292	2,068	60.41	.26	4.23	19.59	1.92	13.59
453	.....do..........	10.01	8.88	.06	81.05	20.64	14,973	10,430	49	640	2,903	50	901	69.66	.33	4.27	19.39	.83	6.02
456	.....do..........	9.26	9.41	.22	81.11	21.87	15,135	9,657	44	656	3,527	196	1,055	63.81	.29	4.33	23.30	1.30	6.97
32	Ind. T. No. 3......	7.80	12.10	.00	80.10	25.31	14,588	9,222	73	608	3,262	0	1,423	63.22	.50	4.17	22.36	.00	9.75
52	Ind. T. No. 4......	7.14	12.64	.21	80.01	26.05	13,961	8,633	101	620	3,457	225	925	61.84	.72	4.44	24.76	1.61	6.63
437	Ind. T. No. 8......	9.83	9.40	.00	80.77	20.87	15,140	9,734	40	621	2,705	0	2,040	64.29	.26	4.10	17.87	.00	13.48
449	Ind. T. No. 9......	9.29	10.03	.17	80.51	23.77	15,730	10,256	56	560	3,314	165	1,379	65.20	.35	3.56	21.07	1.05	8.77
450	.....do..........	10.07	9.60	.05	80.28	22.18	15,817	10,719	50	545	3,109	45	1,349	67.77	.32	3.44	19.66	.28	8.53
45	Iowa No. 1........	8.67	10.63	.12	80.58	21.81	14,320	9,049	151	572	2,442	107	1,999	63.19	1.05	3.99	17.05	.75	13.97
67	Iowa No. 2........	8.10	11.48	.09	80.33	23.14	14,162	8,730	279	650	3,137	85	1,281	61.64	1.97	4.59	22.15	.62	9.03
49	Iowa No. 3........	7.18	13.12	.04	79.66	26.00	14,210	8,691	223	645	3,222	43	1,386	61.16	1.57	4.54	22.67	.30	9.76
47	Iowa No. 4........	7.63	12.31	.10	79.96	24.63	14,157	8,643	242	606	2,906	101	1,659	61.05	1.71	4.28	20.53	.71	11.72
66	.....do..........	7.49	12.27	.06	80.18	26.48	14,641	8,710	235	666	3,621	65	1,344	59.49	1.61	4.55	24.73	.45	9.17
55	Iowa No. 5........	7.83	11.66	.28	80.23	23.69	14,233	8,846	290	644	2,709	272	1,472	62.10	2.03	4.52	19.03	1.91	10.41
601	Jamestown No. 1..	9.49	8.84	.04	81.63	22.11	15,357	10,594	20	604	2,408	36	1,695	68.98	.13	3.93	15.68	.24	11.04
602	.....do..........	10.76	8.01	.00	81.23	19.75	15,165	10,005	25	619	2,457	0	2,059	65.97	.17	4.08	16.20	.00	13.58
603	Jamestown No. 3..	10.74	8.52	.03	80.71	21.00	15,852	10,130	27	582	2,646	26	2,441	63.90	.17	3.67	16.69	.17	15.40
604	.....do..........	11.25	8.11	.16	80.48	19.80	15,812	10,845	26	584	2,628	128	1,601	68.59	.16	3.69	16.62	.81	10.13
605	.....do..........	9.61	10.03	.06	80.30	23.29	15,851	10,130	28	583	2,912	57	2,141	63.91	.18	3.68	18.37	.36	13.50
606	.....do..........	6.96	12.73	.06	80.25	31.81	15,838	10,864	29	518	2,603	78	1,746	68.61	.18	3.27	16.43	.49	11.02
607	.....do..........	7.04	13.16	.00	79.80	31.74	15,829	10,912	28	526	2,872	0	1,491	68.94	.18	3.32	18.14	.00	9.42
608	Jamestown No. 4..	6.26	13.95	.00	79.79	34.96	15,680	10,178	29	554	3,373	0	1,546	64.91	.19	3.53	21.51	.00	9.86
609	.....do..........	....	....	....	....	....	15,720	10,207	30	569	....	....	....	64.93	.19	3.62	....	....	....
610	.....do..........	6.73	13.52	.00	79.75	32.74	15,735	10,430	29	574	3,725	0	977	66.29	.18	3.65	23.67	.00	6.21
611	.....do..........	7.79	12.04	.00	80.17	28.40	15,743	10,642	27	565	3,060	0	1,449	67.60	.17	3.59	19.43	.00	9.21
612	.....do..........	7.66	12.49	.00	79.85	28.87	15,738	10,468	28	563	3,035	0	1,644	66.52	.18	3.58	19.28	.00	10.44
613	.....do..........	7.62	12.56	.00	79.82	29.02	15,737	10,236	25	569	3,148	0	1,759	65.04	.16	3.62	20.00	.00	11.18
614	.....do..........	6.81	13.40	.00	79.79	32.40	15,765	10,970	24	568	3,437	0	766	69.58	.15	3.61	21.80	.00	4.86
615	.....do..........	7.38	12.60	.00	80.02	29.92	15,733	10,768	25	572	3,411	0	957	68.44	.16	3.64	21.68	.00	6.08
616	.....do..........	7.88	12.06	.00	80.06	28.09	15,743	10,488	21	575	3,236	0	1,423	66.62	.13	3.65	20.56	.00	9.04
617	.....do..........	9.58	10.36	.00	80.06	23.05	15,748	10,806	24	561	2,379	0	1,978	68.62	.15	3.56	15.11	.00	12.56
618	.....do..........	9.58	9.77	.00	80.65	23.03	15,749	11,603	25	557	2,261	0	1,298	73.71	.16	3.53	14.36	.00	8.24

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Analysis of the dry gases (per cent). Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Nitrogen (by difference) (N_2).	Pounds of dry gases per pound of combustible.	Heat balance. British thermal units. Total.	Absorbed by boiler.	Loss of heat due to— Moisture. In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.	Per cent. Absorbed by boiler.	Loss of heat due to— Moisture. In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.
1	2	88 (84)	89 (85)	90 (86)	91 (88)	92	93	94	95	96	97	98	99	100	101	102	103	104	105
619	Jamestown No. 4	9.01	10.63	0.00	80.36	24.44	15,751	11,028	26	564	2,596	0	1,535	70.01	0.17	3.58	16.49	0.00	9.75
627	Jamestown No. 6	7.55	12.25	.00	80.20	29.19	15,757	10,893	33	608	4,435	0	—207	69.13	.21	3.86	28.15	.00	—1.32
630	.....do	5.97	14.16	.00	79.87	26.78	15,783	10,806	31	563	4,052	0	331	68.47	.20	3.57	25.67	.00	2.09
631	.....do	11.61	7.05	.11	81.20	19.12	15,780	10,748	39	591	2,712	85	1,600	68.11	.25	3.75	17.19	.54	10.14
620	Jamestown No. 7	10.00	9.59	.00	80.41	22.22	15,805	10,970	26	564	2,613	0	1,632	69.41	.16	3.57	16.53	.00	10.33
621	.....do	8.58	11.01	.00	80.41	25.75	15,801	10,024	37	579	3,374	0	1,787	63.44	.24	3.66	21.35	.00	11.31
623	.....do	10.74	8.70	.04	80.52	20.66	15,792	10,739	25	580	2,820	33	1,595	68.00	.16	3.67	17.86	.21	10.10
624	.....do	8.78	10.94	.00	80.28	25.23	15,791	9,763	24	597	3,778	0	1,629	61.83	.15	3.78	23.93	.00	10.31
625	.....do	8.58	11.12	.06	80.24	26.50	15,771	10,979	30	563	3,464	68	653	69.62	.19	3.60	21.97	.43	4.14
626	.....do	6.85	12.73	.10	80.32	31.47	15,763	10,169	27	595	4,712	129	130	64.51	.17	3.77	29.90	.82	.83
639	Jamestown No. 11	10.98	8.38	.04	80.60	20.64	15,921	10,777	50	558	2,383	75	2,078	67.69	.31	3.51	14.97	.47	13.05
6	Kans. No. 1	7.22	11.90	.07	80.81	25.01	15,648	9,280	90	621	3,323	81	1,649	61.60	.58	4.13	22.08	.54	10.96
7	.....do	7.37	11.88	.08	80.67	26.95	14,874	10,092	76	613	3,355	89	644	67.85	.51	4.15	22.56	.60	4.33
5	Kans. No. 2	6.95	11.95	.00	81.10	28.17	14,943	8,931	69	629	3,535	0	1,777	59.77	.46	4.21	23.66	.00	11.90
13	.....do	7.94	10.95	.00	81.11	25.74	15,378	9,831	87	652	3,268	0	1,540	63.93	.57	4.24	21.25	.00	10.01
438	Kans. No. 2B	9.73	9.36	.00	80.91	20.89	14,909	9,810	82	760	2,898	0	1,367	65.80	.55	5.09	19.43	.00	9.12
437	.....do	8.51	10.79	.01	80.69	23.78	15,049	9,763	169	626	3,196	0	1,295	64.88	1.12	4.16	21.24	.00	8.60
496	.....do	9.51	9.67	.07	80.75	21.33	15,184	10,169	121	608	3,082	61	1,143	66.97	.80	4.00	20.30	.40	7.53
3	Kans. No. 3	7.52	12.20	.08	80.20	26.65	15,082	8,903	31	616	3,206	60	2,266	59.03	.20	4.08	21.26	.40	15.03
4	.....do	6.80	12.68	.02	80.50	29.38	15,120	8,851	33	697	3,168	24	2,347	58.54	.21	4.61	20.95	.16	15.53
56	Kans. No. 4	5.90	13.54	.21	80.35	31.01	14,690	9,184	87	626	3,508	269	1,005	62.52	.59	4.27	23.88	1.84	6.85
72	Kans. No. 5	7.84	12.05	.14	79.97	25.23	15,013	10,159	68	640	3,416	146	585	67.67	.45	4.26	22.75	.97	3.90
311	Kans. No. 6	7.79	11.52	.09	80.60	25.30	14,880	9,561	140	621	2,879	94	1,574	64.25	.94	4.18	19.35	.63	10.59
323	.....do	10.51	8.17	.30	81.02	19.05	14,597	9,380	193	627	2,222	232	2,043	64.31	1.32	4.31	14.92	1.66	13.71

60	Ky. No. 1	8.22	10.70	.21	80.87	24.59	15,295	9,590	40	627	2,768	211	2,050	62.76	.26	4.10	18.10	1.38	13.40
255	Ky. No. 1C	11.10	7.65	.09	81.16	18.97	15,303	9,734	64	668	2,868	69	1,900	63.61	.42	4.37	18.74	.45	12.41
263	do	8.72	10.51	.13	80.64	23.75	15,284	10,459	66	644	3,032	126	957	68.44	.43	4.21	19.84	.82	6.26
265	do	9.24	10.91	.12	79.73	22.53	15,288	10,082	62	657	3,190	110	1,187	65.95	.41	4.30	20.87	.72	7.75
57	Ky. No. 2	8.64	10.24	.23	80.89	22.29	14,745	8,913	118	638	2,540	209	2,327	60.45	.80	4.33	17.23	1.42	15.77
76	do	8.59	10.74	.20	80.47	22.57	14,572	9,087	118	598	2,798	184	1,792	62.37	.78	4.10	19.19	1.26	12.30
64	Ky. No. 3	8.45	10.94	.33	80.28	22.40	14,609	9,164	125	641	2,862	202	1,515	62.73	.86	4.39	19.59	2.07	10.36
62	Ky. No. 4	6.40	13.49	.34	79.77	29.67	14,960	9,521	93	602	3,716	416	612	63.65	.62	4.03	24.84	2.77	4.09
276	Ky. No. 5	10.35	9.02	.20	80.43	20.01	15,169	10,256	69	611	2,848	162	1,223	67.61	.45	4.03	18.77	1.07	8.07
277	do	10.06	8.80	.24	80.90	20.43	15,146	10,748	78	601	2,751	199	769	70.96	.52	3.97	18.16	1.31	5.08
270	Ky. No. 6	10.74	8.63	.07	80.56	19.45	14,933	10,063	70	656	3,011	55	1,078	67.39	.47	4.39	20.16	.37	7.22
271	do	10.55	8.77	.08	80.60	19.76	14,932	9,976	74	652	3,035	64	1,131	66.81	.50	4.37	20.33	.43	7.56
278	Ky. No. 7						14,455	10,082	157	614				69.75	1.09	4.24			
279	do	9.30	9.36	.10	81.24	20.94	14,468	9,705	149	605	2,704	85	1,220	67.08	1.03	4.18	18.69	.59	8.43
434	Ky. No. 8	10.67	8.09	.14	81.10	19.37	15,269	9,773	85	594	2,403	110	2,304	64.01	.56	3.89	15.73	.72	15.09
443	do	9.98	8.79	.09	81.14	20.79	15,297	10,005	85	616	3,034	76	1,481	65.40	.56	4.03	19.83	.50	9.68
462	Ky. No. 9B	10.36	8.34	.07	81.23	19.13	14,690	9,628	129	639	2,580	54	1,660	65.54	.88	4.35	17.56	.37	11.30
222	Md. No. 1	10.27	9.28	.10	80.35	21.45	15,681	10,236	29	518	2,831	87	1,980	65.28	.18	3.30	18.06	.55	12.63
231	do	11.81	7.70	.04	80.45	19.00	15,691	10,758	57	526	2,549	31	1,770	68.56	.36	3.35	16.25	.20	11.28
232	do	11.96	7.20	.08	80.76	18.69	15,676	10,608	52	523	2,422	60	2,016	67.64	.33	3.34	15.45	.38	12.86
490	Md. No. 2	11.23	7.90	.10	80.77	19.86	15,837	10,854	35	583	2,908	80	1,377	68.54	.22	3.68	18.36	.51	8.69
493	do	11.37	7.58	.02	81.03	19.53	15,843	10,961	107	568	2,873	0	1,334	69.18	.68	3.59	18.13	.00	8.42
518	do	10.85	8.34	.16	80.65	20.34	15,796	11,811	61	571	2,416	132	805	74.77	.39	3.61	15.29	.84	5.10
12	Mo. No. 1	8.50	10.90	.00	80.60	23.39	14,867	9,850	125	656	2,997	0	1,239	66.26	.83	4.42	20.16	.00	8.33
23	do	8.97	11.05	.00	79.98	22.41	14,938	9,368	101	617	2,452	0	2,400	62.71	.67	4.13	16.42	.00	16.07
15	do	7.97	11.75	.00	80.28	25.27	14,967	9,502	126	667	3,297	0	1,375	63.49	.84	4.45	22.03	.00	9.19
37	Mo. No. 2	7.36	12.52	.05	80.07	25.60	14,234	8,923	245	637	3,457	53	919	62.69	1.72	4.47	24.28	.37	6.47
44	do	9.48	9.65	.16	80.71	19.94	14,292	9,028	201	604	1,995	130	2,334	63.17	1.41	4.23	13.96	.91	16.32
78	Mo. No. 3	5.42	14.62	.02	79.94	34.36	13,817	8,720	437	644	4,528	28	−540	63.11	3.16	4.66	32.05	.20	−3.18
77	do	7.31	12.48	.15	80.06	25.97	14,102	8,334	387	665	3,484	160	1,072	59.10	2.74	4.72	24.71	1.13	7.60
70	Mo. No. 4	7.92	11.53	.15	80.40	24.92	15,155	9,280	197	689	3,412	153	1,424	61.24	1.30	4.55	22.51	1.01	9.39
319	Mo. No. 5	7.55	12.05	.04	80.36	25.18	14,284	9,039	244	630	2,961	41	1,369	63.28	1.71	4.41	20.73	.29	9.58
320	do	8.88	10.24	.00	80.83	21.65	14,292	9,271	222	631	2,572	0	1,596	64.87	1.55	4.41	18.00	.00	11.17
326	Mo. No. 6	7.91	11.31	.03	80.75	24.12	14,408	9,309	251	630	3,248	0	970	64.61	1.74	4.37	22.54	.00	6.74
327	do	8.61	10.41	.03	80.95	22.54	14,555	8,981	225	684	2,927	0	1,788	61.70	1.55	4.85	20.11	.00	12.29
329	Mo. No. 7A	9.57	9.36	.03	81.04	20.23	14,461	9,000	309	626	2,544	0	1,983	62.24	2.13	4.33	17.59	.00	13.71
330	do	9.81	8.96	.00	81.23	19.81	14,462	8,971	324	635	2,582	0	1,950	62.03	2.24	4.39	17.85	.09	13.49
332	Mo. No. 7B	10.27	7.91	.17	81.65	18.58	14,252	8,073	341	682	3,086	128	1,942	56.64	2.39	4.79	21.65	.90	13.63
486	Mo. No. 10	9.97	9.26	.02	80.75	19.96	14,470	8,122	77	640	2,724	0	2,907	56.13	.53	4.42	18.83	.00	20.09
470	Mont. No. 2	9.94	9.19	.02	80.85	19.43	13,768	9,377	167	633	2,765	0	826	68.11	1.21	4.60	20.08	.00	6.00
477	Mont. No. 3	10.48	8.53	.07	80.92	18.33	13,682	9,000	160	634	2,653	52	1,183	65.78	1.17	4.63	19.39	.38	8.65
27	N. Mex. No. 1	9.55	10.07	1.11	79.27	18.37	13,947	8,284	119	631	2,142	830	1,869	59.39	1.37	4.52	15.36	5.95	13.41
26	N. Mex. No. 2	7.79	12.95	.07	79.19	24.70	14,071	8,237	171	653	2,804	71	2,135	58.54	1.21	4.64	19.93	.50	15.18
30	do	7.15	12.70	.01	80.14	28.02	14,890	9,216	113	693	3,497	11	1,360	61.89	.76	4.65	23.49	.08	9.13
396	N. Mex. No. 3A	8.85	9.90	.04	81.21	23.16	14,890	10,005	46	678	3,252	38	871	67.19	.31	4.55	21.84	.26	5.85
389	N. Mex. No. 3B	8.52	8.52	.20	82.76	23.48	14,870	10,178	50	654	3,302	193	493	68.45	.34	4.40	22.21	1.30	3.30
391	do	9.51	6.90	.56	83.03	20.41	14,881	10,294	40	654	2,861	467	565	69.18	.27	4.39	19.23	3.14	3.79
392	do	9.77	8.66	.12	81.45	20.86	14,985	9,812	77	672	3,229	102	1,093	65.48	.51	4.48	21.55	.68	7.30
397	N. Mex. No. 4A	9.32	9.97	.12	80.59	21.88	14,879	9,502	37	683	3,109	107	1,441	63.86	.25	4.59	20.89	.72	9.69
398	do	10.06	9.07	.12	80.75	20.34	14,918	9,821	60	680	2,865	99	1,393	65.83	.40	4.56	19.21	.66	9.34
395	N. Mex. No. 4B	8.10	10.96	.05	80.89	25.13	14,978	9,754	54	686	3,631	51	802	65.12	.36	4.58	24.24	.34	5.36
387	N. Mex. No. 5	9.48	7.31	.14	83.07	21.81	15,148	9,879	37	656	3,088	125	1,363	65.22	.24	4.33	20.39	.83	8.99
33	N. Dak. No. 1	4.74	15.96	.00	79.30	37.41	12,466	6,634	835	544	3,842	0	611	53.22	6.70	4.37	30.81	.00	4.90

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Analysis of the dry gases (per cent). Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Nitrogen (by difference) (N_2).	Pounds of dry gases per pound of combustible.	Heat balance. British thermal units. Total.	Absorbed by boiler.	Loss of heat d[...] Moisture. In fuel.	Of burning hydrogen.	Carried away in dry gases.						[...]ent. [...] heat due to— Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.
1	2	88 (84)	89 (85)	90 (86)	91 (88)	92	93	94	95	96	97						103	104	105
206	N. Dak. No. 3	9.56	9.60	0.00	80.84	19.19	12,555	7,214	818	520	2,330	0	1,673	57.46	6.52	4.14	18.56	0.00	13.32
191	Ohio No. 1	8.95	9.08	.20	81.77	20.87	14,216	9,696	125	632	2,309	171	1,285	68.19	.88	4.45	16.24	1.20	9.04
192	....do	10.33	7.72	.22	81.73	18.62	14,436	9,097	137	658	2,239	167	2,138	63.02	.95	4.56	15.51	1.16	14.80
193	Ohio No. 2	10.96	7.26	.11	81.67	17.72	14,367	9,242	146	627	2,143	79	2,130	64.33	1.02	4.36	14.92	.55	14.82
197	....do	9.45	8.43	.15	81.97	20.70	14,331	8,962	136	631	2,300	127	2,175	62.54	.95	4.40	16.05	.89	15.17
203	Ohio No. 3	12.28	5.61	.41	81.70	16.01	14,493	9,667	138	621	2,033	265	1,769	66.70	.95	4.28	14.03	1.83	12.21
188	Ohio No. 4	11.01	6.71	.27	82.01	18.15	14,930	9,551	55	633	2,365	199	2,127	63.97	.37	4.24	15.84	1.33	14.25
201	....do	10.16	8.47	.14	81.23	20.08	15,069	9,966	55	622	2,299	114	2,012	66.14	.36	4.13	15.26	.76	13.35
202	....do	10.57	7.77	.16	81.20	18.56	14,923	10,121	52	630	2,187	120	1,823	67.82	.35	4.15	14.66	.80	12.22
219	....do	12.74	5.96	.33	80.98	15.93	15,052	9,821	59	641	2,003	211	2,317	65.25	.39	4.26	13.31	1.40	15.39
220	....do	12.05	6.89	.17	80.89	17.01	15,037	9,502	64	651	2,294	117	2,409	63.19	.42	4.33	15.26	.78	16.02
221	....do	11.40	7.27	.19	81.14	17.88	15,038	......	64	648	2,356	137	......	......	.43	4.31	15.67	.91	......
186	Ohio No. 5	12.26	5.22	.48	82.04	16.24	14,921	9,502	63	622	2,093	315	2,326	63.66	.42	4.17	14.03	2.11	15.59
187	....do	11.34	7.07	.06	81.53	18.10	14,917	9,618	73	642	2,680	44	1,860	64.48	.49	4.31	17.97	.29	12.46
189	....do	11.42	6.61	.17	81.80	17.75	14,888	9,985	70	617	2,211	122	1,883	67.07	.47	4.14	14.85	.82	12.65
190	....do	11.39	6.22	.24	82.15	17.70	14,903	9,889	67	625	2,324	172	1,826	66.35	.45	4.19	15.60	1.15	12.26
284	Ohio No. 6	8.58	10.85	.13	80.44	23.26	14,534	10,236	58	656	3,146	124	612	69.01	.39	4.42	21.22	.84	4.12
253	....do	10.04	8.82	.23	80.91	20.05	14,965	9,589	49	686	2,979	188	1,474	64.08	.33	4.58	19.90	1.26	9.85
268	Ohio No. 7	10.04	9.42	.14	80.40	19.98	14,708	10,014	109	672	2,983	114	816	68.09	.74	4.57	20.28	.78	5.54
269	....do	9.61	10.20	.23	79.96	20.60	14,696	9,715	106	675	3,159	193	839	66.15	.72	4.60	21.51	1.31	5.71
287	Ohio No. 8	9.75	9.40	.12	80.73	20.25	14,473	9,734	140	666	2,843	99	991	67.26	.97	4.60	19.64	.68	6.85
246	Ohio No. 9A	10.74	7.36	.09	81.81	18.57	14,747	9,715	89	583	2,474	68	1,818	65.89	.60	3.95	16.77	.46	12.34
249	....do	10.15	8.25	.07	81.43	19.06	14,766	9,618	98	576	2,520	60	1,[illegible]	65.14	.66	3.90	17.13	.38	12.79

250	.....do............	10.02	8.83	.01	81.14	20.03	14,758	9,956	95	589	2,779	0	1,339	67.46	.64	3.99	18.83	.00	9.08
252	.....do............	11.17	7.22	.06	81.55	17.99	14,774	9,754	92	584	2,539	44	1,761	66.02	.62	3.95	17.18	.30	11.93
224	Ohio No. 9B	10.12	9.25	.05	80.58	19.52	14,454	9,628	132	621	2,422	40	1,611	66.61	.91	4.30	16.76	.28	11.14
241	.....do............	10.36	8.46	.07	81.11	19.20	14,629	9,821	122	633	2,557	55	1,441	67.18	.83	4.33	17.48	.38	9.85
243	.....do............	10.14	8.29	.13	81.44	19.24	14,466	9,638	27	635	2,397	102	1,667	66.62	.19	4.39	16.57	.71	11.52
244	.....do............	9.90	8.55	.08	81.47	19.78	14,467	9,522	36	644	2,616	64	1,585	65.82	.25	4.45	18.08	.44	10.96
469	Ohio No. 10.......	10.86	8.10	.06	80.98	18.01	14,636	10,034	63	708	2,710	44	1,077	68.56	.43	4.84	18.51	.30	5.36
474	Ohio No. 11.......	9.64	9.52	.00	80.84	20.72	14,746	9,792	54	630	2,785	0	1,485	66,41	.37	4.27	18.89	.00	10.06
475	.....do............	9.75	9.32	.00	80.93	20.18	14,586	9,860	54	620	2,765	0	1,287	67.60	.37	4.25	18.96	.00	8.82
483	Ohio No. 12.......	10.59	8.18	.08	81.15	18.86	14,883	10,043	55	658	2,757	61	1,309	67.48	.37	4.42	18.52	.41	8.80
1	Pa. No. 1..........	6.50	13.30	.00	80.20	33.97	15,848	9,647	15	511	4,075	0	1,600	60.87	.10	3.22	25.71	.00	10.10
2	Pa. No. 2..........	8.70	10.40	.07	80.83	25.46	15,802	10,236	8	510	2,778	73	2,197	64.78	.05	3.23	17.58	.46	13.90
36	Pa. No. 3..........	7.14	13.16	.00	79.70	30.12	15,599	10,265	47	610	4,026	0	651	65.81	.30	3.91	25.81	.00	4.17
74	Pa. No. 4..........	8.87	10.42	.27	80.44	23.57	15,619	10,178	42	632	2,900	259	1,608	65.17	.27	4.04	18.57	1.66	10.29
207	.....do............	11.58	6.62	.16	81.64	18.39	15,518	10,710	33	604	2,048	119	2,004	69.01	.21	3.89	13.20	.77	12.92
208	.....do............	11.51	7.56	.06	80.87	18.70	15,532	10,970	31	608	2,118	45	1,760	70.63	.20	3.91	13.64	.29	11.33
209	.....do............	11.85	7.25	.12	80.78	18.10	15,526	10,603	35	613	2,168	88	2,019	68.29	.23	3.95	13.96	.57	13.00
286	Pa. No. 5..........	10.58	8.36	.21	80.85	19.73	15,297	11,009	62	650	2,704	168	704	71.97	.41	4.25	17.68	1.10	4.59
194	.....do............	11.38	6.39	.36	81.87	18.18	15,297	9,860	42	632	2,260	265	2,238	64.46	.27	4.13	14.78	1.73	14.63
195	.....do............	11.41	6.70	.44	81.45	18.03	15,314	10,005	40	617	2,016	321	2,315	65.33	.26	4.03	13.17	2.10	15.11
217	Pa. No. 6..........	9.28	9.08	.30	81.34	22.04	15,303	10,159	37	604	2,544	270	1,689	66.39	.24	3.95	16.62	1.76	11.04
218	.....do............	12.47	6.84	.27	80.42	16.75	15,261	10,565	42	610	2,066	182	1,796	69.23	.28	4.00	13.54	1.19	11.76
333	.....do............	9.44	9.80	.20	80.56	22.00	15,198	9,976	76	664	3,416	179	887	65.64	.50	4.37	22.48	1.18	5.83
198	Pa. No. 7..........	10.08	8.44	.13	81.35	21.18	15,689	10,478	53	590	2,714	112	1,742	66.78	.34	3.76	17.30	.71	11.11
307	.....do............	8.19	9.69	.04	82.08	26.16	15,731	10,777	93	597	3,215	43	1,006	68.51	.59	3.80	20.43	.27	6.40
199	.....do............	10.75	7.53	.04	81.68	20.34	15,626	10,507	73	591	2,436	33	1,986	67.24	.47	3.78	15.59	.21	12.71
236	Pa. No. 8..........	11.16	8.26	.00	80.58	20.21	15,900	10,816	34	551	2,673	0	1,826	68.02	.21	3.47	16.81	.00	11.49
237	.....do............	10.83	8.58	.00	80.59	20.79	15,898	10,642	45	547	2,610	0	2,054	66.94	.28	3.44	16.42	.00	12.92
238	.....do............	9.62	9.81	.06	80.51	23.16	15,900	10,903	53	556	3,157	57	1,174	68.57	.33	3.50	19.86	.36	7.38
239	.....do............	10.36	9.03	.00	80.61	21.64	15,867	10,343	35	546	2,872	0	2,071	65.18	.22	3.44	18.10	.00	13.06
242	.....do............	10.01	9.45	.02	80.52	22.30	15,774	10,768	0	473	2,762	0	1,771	68.26	.00	3.00	17.51	.00	11.23
227	Pa. No. 10.........	11.16	7.82	.15	80.87	18.74	15,335	10,652	46	641	2,496	114	1,386	69.46	.30	4.18	16.28	.74	9.04
228	.....do............	11.48	7.52	.09	80.91	18.34	15,331	10,710	41	634	2,315	67	1,564	69.86	.27	4.14	15.10	.44	10.19
229	.....do............	11.24	7.63	.09	81.04	18.74	15,360	10,130	33	654	2,699	68	1,776	65.95	.21	4.26	17.57	.44	11.57
472	Pa. No. 15.........	7.84	11.57	.17	80.42	26.47	15,545	10,207	29	558	3,697	184	870	65.66	.19	3.59	23.78	1.18	5.60
473	.....do............	8.09	11.28	.08	80.55	26.48	15,766	10,478	36	559	3,368	87	1,238	66.46	.23	3.55	21.36	.55	7.85
467	.....do............	9.96	9.15	.03	80.86	21.48	15,571	10,912	58	558	2,789	26	1,228	70.08	.37	3.58	17.91	.17	7.89
468	Pa. No. 16.........	10.77	8.38	.04	80.81	20.18	15,614	10,652	80	564	2,717	33	1,568	68.22	.51	3.61	17.40	.21	10.05
471	.....do............	9.84	9.44	.02	80.70	21.86	15,372	10,652	63	570	2,938	0	1,149	69.29	.41	3.71	19.11	.00	7.48
496	Pa. No. 17.........	8.97	10.39	.03	80.61	23.62	15,474	10,391	55	651	3,322	29	1,026	67.15	.35	4.21	21.47	.19	6.63
506	.....do............	8.31	10.62	.04	81.03	25.36	15,462	9,812	43	647	3,634	42	1,284	63.46	.28	4.19	23.50	.27	8.30
499	Pa. No. 18.........	11.25	7.98	.00	80.77	19.80	15,709	10,352	64	588	3,265	0	1,440	65.90	.41	3.74	20.78	.00	9.17
515	.....do............	9.99	9.40	.06	80.55	22.01	15,738	10,256	96	566	3,597	54	1,169	65.17	.61	3.60	22.85	.34	7.43
498	Pa. No. 19.........	9.14	10.06	.04	80.76	22.75	15,372	10,121	48	631	3,205	37	1,330	65.84	.31	4.11	20.85	.24	8.65
508	.....do............	8.96	10.27	.02	80.75	23.44	15,499	10,420	78	615	3,291	0	1,095	67.23	.50	3.97	21.23	.00	7.07
512	Pa. No. 20.........	9.46	9.64	.10	80.80	23.25	15,951	10,391	54	592	3,621	95	1,198	65.14	.34	3.71	22.70	.60	7.51
514	.....do............	11.26	7.79	.11	80.84	19.37	15,727	8,749	44	609	3,408	86	2,831	55.63	.28	3.87	21.67	.55	18.00
510	Pa. No. 22.........	8.53	10.68	.43	80.36	23.40	15,569	9,976	82	604	3,510	411	985	64.08	.53	3.88	22.54	2.64	6.33
401	R. I. No. 1.........	6.78	13.94	.00	79.28	34.84	14,001	7,436	36	92	4,147	0	2,290	53.11	.26	.66	29.62	.00	16.35
344	Tenn. No. 1........	8.91	10.15	.23	80.71	22.40	14,959	9,956	77	661	3,150	210	905	66.56	.51	4.42	21.06	1.40	6.05
345	.....do............	8.28	10.97	.09	80.66	24.39	14,947	9,879	66	676	3,770	90	466	66.09	.44	4.52	25.22	.61	3.12
346	.....do............	8.77	10.39	.05	80.79	23.23	14,964	10,169	70	670	3,440	47	568	67.96	.47	4.48	22.99	.31	3.79
411	.....do............	9.96	8.66	.10	81.28	20.74	15,021	10,555	29	624	3,061	84	668	70.26	.19	4.15	20.39	.56	4.45

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Analysis of the dry gases (per cent).				Pounds of dry gases per pound of combustible.	Heat balance.												
							British thermal units.							Per cent.					
							Total.	Absorbed by boiler.	Loss of heat due to—					Absorbed by boiler.	Loss of heat due to—				
									Moisture.						Moisture.				
		Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Nitrogen (by difference) (N_2).				In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.		In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.
1	2	88 (84)	89 (85)	90 (86)	91 (88)	92	93	94	95	96	97	98	99	100	101	102	103	104	105
409	Tenn. No. 1	8.53	10.72	0.00	80.75	24.50	15,012	10,217	38	647	3,622	0	488	68.06	0.25	4.31	24.13	0.00	3.25
367	Tenn. No. 2	8.65	8.95	.73	81.67	22.06	15,092	9,136	70	654	3,171	659	1,402	60.54	.46	4.33	21.01	4.37	9.29
368	.....do	9.38	9.73	.00	80.89	22.17	15,092	10,159	74	632	2,735	0	1,492	67.31	.49	4.19	18.12	.00	9.89
369	.....do	8.91	10.15	.05	80.89	23.17	15,092	10,207	75	632	2,836	47	1,295	67.63	.50	4.19	18.79	.31	8.58
349	Tenn. No. 3	10.73	6.82	1.25	81.20	17.25	14,898	9,164	79	649	2,012	876	2,118	61.51	.53	4.36	13.50	5.88	14.22
350	.....do	10.40	8.31	.28	81.01	19.32	14,879	9,996	100	668	2,597	220	1,298	67.18	.67	4.49	17.45	1.48	8.73
355	Tenn. No. 4	9.02	9.61	.27	81.10	22.33	14,964	10,034	99	654	2,739	246	1,192	67.05	.66	4.37	18.31	1.64	7.97
356	.....do	9.75	9.11	.12	81.02	21.10	14,969	10,169	90	666	2,836	103	1,105	67.98	.60	4.45	18.95	.69	7.38
405	.....do	8.41	10.84	.00	80.75	24.92	15,102	10,420	42	606	3,511	0	523	69.00	.28	4.01	23.25	.00	3.46
352	Tenn. No. 5	8.93	10.00	.21	80.86	22.52	15,173	9,956	86	641	2,800	193	1,497	65.62	.57	4.23	18.45	1.27	9.86
357	.....do	8.34	10.46	.18	81.02	24.21	15,225	9,551	90	652	3,184	178	1,570	62.73	.59	4.28	20.92	1.17	10.31
358	.....do	8.73	10.11	.10	81.06	23.36	15,202	10,159	105	646	2,994	95	1,203	66.83	.69	4.25	19.70	.62	7.91
379	Tenn. No. 6	8.95	10.48	.02	80.55	23.79	15,327	10,903	43	604	2,467	0	1,310	71.14	.28	3.94	16.10	.00	8.54
381	.....do	7.65	12.01	.06	80.28	27.53	15,321	9,696	51	620	3,178	68	1,708	63.28	.33	4.05	20.74	.44	11.16
372	Tenn. No. 7A	9.90	9.51	.27	80.32	20.19	14,969	9,763	47	663	2,743	222	1,531	65.22	.31	4.43	18.32	1.48	10.24
373	.....do	10.68	7.75	.08	81.49	18.91	14,849	9,715	49	657	2,737	61	1,630	65.43	.33	4.42	18.43	.41	10.98
374	.....do	9.03	10.11	.00	80.86	22.65	14,967	10,121	52	640	2,751	0	1,403	67.62	.35	4.28	18.38	.00	9.37
406	Tenn. No. 7B	8.63	10.48	.00	80.89	24.28	15,121	10,063	51	667	3,508	0	832	66.55	.34	4.41	23.20	.00	5.50
384	Tenn. Nos. 8A and 8B	8.16	11.07	.00	80.77	24.86	15,059	9,840	35	569	2,315	0	2,298	65.37	.23	3.78	15.38	.00	15.24
385	.....do	7.75	11.17	.05	81.03	26.21	15,157	9,599	34	609	2,617	54	2,244	63.33	.22	4.02	17.27	.36	14.80
388	.....do	8.93	8.13	.09	82.85	23.14	15,125	10,159	43	667	3,360	85	811	67.17	.28	4.41	22.21	.56	5.37
363	Tenn. No. 9A	9.13	10.23	.03	80.61	23.17	15,248	10,111	71	634	3,231	0	1,201	66.31	.47	4.16	21.19	.00	7.87

364	.....do.	9.78	9.40	.09	80.64	21.68	15,283	9,802	56	650	3,265	79	1,431	64.14	.37	4.25	21.36	.52	9.36
365	.....do.	8.34	10.98	.17	80.51	24.98	15,278	9,812	59	644	3,656	173	920	64.24	.39	4.22	22.94	1.13	6.08
398	Tenn. No. 9B	9.46	9.74	.06	80.72	22.48	15,176	10,258	66	616	3,315	55	908	67.58	.44	4.06	21.84	.36	5.72
407	Tenn. No. 10	6.78	12.02	.08	80.18	30.61	14,941	9,987	80	680	4,386	0	790	60.80	.26	4.31	30.36	.00	5.28
408	.....do.	7.34	12.34	.00	80.42	28.79	14,887	10,459	48	680	4,236	0	−575	70.54	.32	4.45	28.57	.00	−3.88
22	Tex. No. 1	8.88	17.40	.00	78.97	53.25	13,724	6,470	408	540	4,485	0	1,767	47.15	3.37	3.98	32.60	.00	12.86
301	Tex. No. 4	8.75	11.24	.00	80.01	30.82	13,781	7,818	845	578	2,618	0	877	61.37	6.64	4.54	20.57	.00	6.88
398	.....do.	10.26	9.02	.00	80.72	17.85	13,787	6,695	855	584	2,489	0	2,340	52.01	6.71	4.50	19.10	.00	17.50
308	.....do.	8.61	10.30	.24	80.26	30.55	12,795	6,759	341	595	2,940	201	1,580	58.05	2.06	4.66	28.17	1.58	14.84
402	Utah No. 2	8.86	10.14	.00	80.98	31.59	13,512	6,988	188	592	3,011	0	2,744	51.67	1.38	4.38	22.28	.00	20.31
403	.....do.	7.12	12.28	.00	80.60	37.21	13,680	8,904	130	578	3,208	0	885	65.04	1.03	4.22	28.62	.00	6.10
404	.....do.	6.31	13.30	.00	80.49	30.68	13,606	8,266	188	573	3,690	0	982	60.75	1.13	4.21	27.06	.00	6.85
261	Va. No. 1	10.31	9.08	.13	80.54	20.16	15,178	10,410	68	684	2,772	98	1,191	68.61	.45	4.18	18.37	.65	7.84
262	.....do.	10.25	8.82	.21	80.72	20.08	15,169	10,382	75	686	2,776	171	1,159	68.25	.40	4.19	18.30	1.13	7.64
247	Va. No. 2	11.48	6.89	.16	81.47	18.22	15,267	10,372	37	688	2,582	118	1,595	67.85	.24	4.14	16.56	.77	10.44
251	.....do.	11.66	6.66	.04	81.60	18.14	15,311	10,098	50	643	2,601	29	1,806	65.91	.38	4.20	17.57	.19	11.80
256	.....do.	11.46	6.63	.26	81.65	18.12	15,304	10,099	68	640	2,531	191	1,769	65.98	.41	4.18	16.54	1.25	11.60
269	.....do.	12.33	5.86	.19	81.68	17.03	15,201	10,024	48	629	2,285	130	2,086	65.94	.39	4.14	15.08	.86	13.71
280	Va. No. 3	9.18	10.23	.12	80.47	23.78	15,651	10,294	24	614	3,116	114	1,489	65.77	.15	3.92	19.91	.73	9.52
283	.....do.	9.57	9.45	.12	80.86	22.38	15,606	10,468	46	610	2,895	109	1,608	66.82	.29	3.90	18.08	.70	10.27
240	Va. No. 4	9.88	8.98	.27	80.87	20.79	15,306	10,084	48	617	2,600	228	1,779	65.55	.30	4.03	16.99	1.49	11.68
248	.....do.	10.68	8.05	.05	81.27	19.88	15,306	10,498	52	624	2,737	40	1,365	68.52	.34	4.08	17.88	.26	8.92
264	.....do.	11.42	6.98	.09	81.51	18.44	14,977	9,850	60	687	2,680	67	1,694	65.77	.40	4.25	17.82	.45	11.31
476	Va. No. 5A	9.76	9.58	.16	80.50	22.57	15,493	10,401	81	518	3,001	147	1,345	67.13	.52	3.35	19.37	.95	8.68
482	.....do.	11.82	6.25	.20	81.73	18.77	15,504	9,338	81	541	2,996	152	2,396	60.23	.52	3.49	19.33	.98	15.45
494	Va. No. 5B	9.66	9.99	.10	80.25	23.01	15,573	10,671	83	517	3,242	94	966	68.52	.53	3.32	20.82	.61	6.20
507	Va. No. 6	8.29	10.92	.04	80.75	25.84	15,691	9,947	58	592	3,777	42	1,275	63.39	.37	3.77	24.07	.27	8.13
290	Wash. No. 1B	8.91	10.51	.07	80.51	21.38	13,748	8,942	286	646	2,591	61	1,222	65.04	2.08	4.70	18.85	.44	8.89
359	Wash. No. 2	9.05	9.10	.23	81.62	21.95	14,880	9,918	49	676	3,077	206	954	66.65	.33	4.54	20.68	1.39	6.41
360	.....do.	10.41	7.92	.30	81.37	19.13	14,882	9,522	56	673	2,594	233	1,804	63.98	.38	4.52	17.43	1.57	12.12
361	.....do.	9.75	9.19	.04	81.02	20.90	14,886	9,725	55	664	2,709	34	1,699	65.33	.37	4.46	18.20	.23	11.41
412	.....do.	7.33	12.00	.06	80.61	27.55	14,940	9,869	41	650	3,974	68	338	66.06	.27	4.35	26.60	.46	2.26
24	W. Va. No. 1	9.95	9.18	.44	80.43	20.37	15,324	9,559	26	617	2,091	368	2,608	62.38	.17	4.02	13.61	2.36	17.46
25	W. Va. No. 2	8.24	11.63	.20	79.93	24.34	15,384	10,178	29	623	2,727	199	1,628	66.16	.19	4.05	17.73	1.29	10.58
28	W. Va. No. 3	7.95	12.00	.00	80.05	26.68	15,454	10,227	38	627	3,353	0	1,209	66.18	.25	4.06	21.70	.00	7.81
31	W. Va. No. 4	8.67	11.03	.24	80.06	24.06	15,601	10,739	37	600	2,876	236	1,113	68.83	.24	3.85	18.43	1.51	7.14
34	W. Va. No. 5	7.77	12.08	.02	80.13	27.18	15,479	10,666	31	618	3,450	22	692	68.91	.20	3.99	22.29	.14	4.47
39	W. Va. No. 6	8.31	12.46	.07	79.16	26.30	15,841	10,642	30	573	3,285	75	1,236	67.18	.19	3.62	20.74	.47	7.80
43	.....do.	10.32	9.50	.09	80.09	21.38	15,848	10,825	29	556	2,319	78	2,041	68.31	.18	3.51	14.63	.49	12.88
51	W. Va. No. 7	8.33	11.30	.00	80.37	25.97	15,730	10,797	39	526	3,146	0	1,222	68.64	.25	3.34	20.00	.00	7.77
53	W. Va. No. 8	8.75	10.71	.09	80.45	24.36	15,564	10,275	76	629	2,813	90	1,681	66.02	.49	4.04	18.08	.58	10.79
60	W. Va. No. 9	8.77	11.11	.06	80.06	24.24	15,584	10,603	49	624	3,364	59	885	68.04	.31	4.01	21.59	.38	5.67
54	W. Va. No. 10	8.80	10.50	.21	80.49	25.60	16,025	10,352	24	547	2,861	214	2,027	64.60	.15	3.41	17.85	1.34	12.65
56	W. Va. No. 11	8.58	11.32	.05	80.05	26.00	15,934	11,347	73	517	3,067	53	857	71.21	.46	3.24	19.37	.33	5.39
46	W. Va. No. 12	10.01	9.84	.16	79.99	22.27	15,953	10,449	21	527	2,481	145	2,330	65.50	.13	3.30	15.55	.91	14.61
59	.....do.	9.14	10.18	.20	80.48	24.13	16,266	10,922	33	614	3,011	197	1,489	67.15	.20	3.77	18.51	1.21	9.16
179	W. Va. No. 13	11.40	7.13	.14	81.33	18.94	15,621	10,729	50	607	2,300	107	1,828	68.68	.32	3.89	14.72	.69	11.70
180	.....do.	11.24	7.46	.14	81.16	19.22	15,630	10,903	63	605	2,283	109	1,667	69.76	.40	3.87	14.61	.70	10.66
178	W. Va. No. 14	10.79	7.52	.16	81.53	19.51	15,403	10,507	38	594	2,355	127	1,782	68.21	.25	3.86	15.29	.82	11.57
181	.....do.	11.08	7.29	.29	81.34	18.80	15,389	9,792	72	605	2,436	221	2,263	63.63	.47	3.93	15.83	1.44	14.70
214	W. Va. No. 15	10.52	8.29	.10	81.09	19.87	15,385	10,545	27	616	2,287	81	1,879	68.54	.18	4.00	14.54	.53	12.21
215	.....do.	10.15	8.15	.26	81.44	20.28	15,413	9,696	36	631	2,477	214	2,359	62.91	.23	4.09	16.07	1.39	15.31
216	.....do.	11.09	6.34	.45	82.12	18.35	15,423	9,300	40	631	2,308	225	2,809	60.30	.26	4.00	14.96	2.17	18.22

TABLE 4.—*Observed data and computed results of steaming tests at St. Louis, Mo., and Norfolk, Va.*—Continued.

[Figures in parenthesis are A. S. M. E. code number.]

No. of test.	Designation of coal.	Analysis of the dry gases (per cent).				Pounds of dry gases per pound of combustible.	Heat balance.												
							British thermal units.							Per cent.					
									Loss of heat due to—						Loss of heat due to—				
									Moisture.						Moisture.				
		Carbon dioxide (CO_2).	Oxygen (O_2).	Carbon monoxide (CO).	Nitrogen (by difference) (N_2).		Total.	Absorbed by boiler.	In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.	Absorbed by boiler.	In fuel.	Of burning hydrogen.	Carried away in dry gases.	Incomplete combustion of carbon.	Radiation and other losses.
1	2	88 (84)	89 (85)	90 (86)	91 (88)	92	93	94	95	96	97	98	99	100	101	102	103	104	105
304	W. Va. No. 16A	11.23	7.67	0.06	81.04	18.77	15,160	11,163	62	647	2,613	46	629	73.64	0.41	4.27	17.24	0.30	4.14
305	do	10.06	9.02	.00	80.92	20.99	15,255	10,903	101	621	2,373	0	1,257	71.47	.66	4.07	15.56	.00	8.24
225	W. Va. No. 17	10.34	9.12	.08	80.46	20.95	15,711	10,932	61	571	2,630	68	1,449	69.58	.39	3.63	16.74	.43	9.23
226	do	9.90	9.60	.06	80.44	21.89	15,722	10,661	61	578	2,895	53	1,474	67.81	.39	3.68	18.41	.34	9.37
230	do	11.02	8.19	.02	80.77	19.80	15,650	10,632	63	571	2,504	16	1,864	67.94	.40	3.65	16.00	.10	11.91
261	W. Va. No. 18	11.93	7.00	.13	80.94	17.91	15,454	11,019	44	616	2,493	94	1,188	71.30	.28	3.98	16.13	.61	7.70
262	do	11.64	7.40	.28	80.68	18.10	15,452	10,806	40	609	2,476	205	1,316	69.93	.26	3.94	16.02	1.33	8.52
285	W. Va. No. 19	9.38	9.58	.04	81.00	23.44	15,668	11,086	35	571	2,993	38	945	70.76	.22	3.64	19.10	.24	6.04
289	do	9.16	10.48	.00	80.36	24.07	15,651	11,057	44	559	2,842	0	1,149	70.65	.28	3.57	18.16	.00	7.34
331	do	10.27	9.08	.00	80.65	21.34	15,782	9,647	65	608	2,776	0	2,686	61.13	.41	3.85	17.59	.00	17.02
272	W. Va. No. 20	9.95	8.92	.14	81.00	21.34	15,455	10,825	32	635	2,663	113	1,187	70.05	.21	4.11	17.23	.73	7.67
273	do	9.34	10.09	.07	80.50	22.76	15,422	10,806	43	637	2,939	65	932	70.07	.28	4.13	19.06	.42	6.04
264	do	11.17	8.02	.05	80.76	19.32	15,415	10,825	51	651	2,564	39	1,285	70.23	.33	4.22	16.63	.25	8.34
266	do	11.63	7.40	.06	80.91	18.57	15,410	10,198	46	657	2,656	45	1,808	66.18	.30	4.26	17.24	.29	11.73
274	W. Va. No. 21	10.29	8.99	.19	80.53	20.25	15,265	10,497	52	649	2,901	156	1,010	68.77	.34	4.25	19.00	1.02	6.62
275	do	10.61	8.33	.04	81.02	19.91	15,250	10,671	57	635	2,595	32	1,260	69.97	.37	4.17	17.01	.21	8.27
296	do	10.01	9.16	.26	80.57	20.60	15,240	10,584	49	622	2,457	218	1,310	69.45	.32	4.08	16.12	1.43	8.60
267	do	11.43	7.45	.08	81.04	18.50	15,380	10,275	63	664	2,859	60	1,459	66.81	.41	4.32	18.59	.39	9.48
446	W. Va. No. 22A	8.42	10.79	.04	80.75	24.68	14,996	9,657	89	657	3,477	40	1,076	64.40	.59	4.38	23.19	.27	7.17
447	do	10.08	8.87	.04	81.01	20.73	14,979	10,246	91	657	2,945	34	1,006	68.40	.61	4.39	19.66	.23	6.71
454	do	10.68	8.20	.25	80.87	19.29	15,126	9,976	78	657	2,713	196	1,506	65.95	.51	4.38	17.94	1.30	9.96
438	W. Va. No. 22B	10.45	8.12	.12	81.31	19.84	15,194	10,236	51	647	2,854	97	1,309	67.37	.34	4.26	18.78	.64	8.61

439	W. Va. No. 23A....	10.06	8.93	.09	80.92	20.69	15,257	9,860	80	641	2,935	76	1,726	64.56	.20	4.20	19.24	.80	11.30
440	.....do..........	9.34	9.51	.12	81.03	22.08	15,233	10,130	89	636	3,062	106	1,268	66.50	.26	4.17	20.04	.71	8.32
444	W. Va. No. 23B....	8.95	10.15	.16	80.74	23.11	15,245	9,880	58	646	3,164	161	1,626	62.84	.38	4.24	20.89	.99	10.68
445	.....do..........	9.59	9.41	.05	80.95	21.77	15,141	10,285	37	648	3,072	44	1,055	67.98	.24	4.28	20.29	.29	6.97
63	Wyo. No. 1........	8.18	11.72	.25	79.85	23.16	13,343	7,755	302	619	2,852	226	1,499	58.12	2.94	4.64	21.37	1.09	11.24
61	Wyo. No. 2........	6.58	12.98	.00	80.44	27.61	13,813	7,619	202	653	3,341	0	1,998	55.16	1.46	4.73	24.19	.00	14.46
196	Wyo. No. 2B.......	7.38	11.52	.11	80.99	24.90	14,170	8,247	176	628	2,916	113	2,090	58.20	1.24	4.43	20.58	.80	14.75
210	.....do..........	9.90	9.16	.06	80.88	19.06	14,251	8,701	172	645	2,383	46	2,304	61.05	1.21	4.53	16.72	.32	16.16
213	.....do..........	10.76	7.20	.53	81.51	16.54	14,066	8,015	168	640	2,211	356	2,676	56.98	1.19	4.55	15.72	2.53	19.03
211	Wyo. No. 3........	7.50	11.60	.10	80.90	22.97	13,095	8,855	283	596	2,630	94	638	67.62	2.16	4.54	20.08	.72	4.88
212	.....do..........	9.47	9.32	.13	81.08	18.02	12,945	8,295	249	586	2,219	95	1,501	64.08	1.92	4.53	17.14	.73	11.60
223	.....do..........	9.74	9.18	.30	80.78	18.33	13,798	8,740	332	625	2,186	224	1,691	63.34	2.41	4.58	15.84	1.62	12.26
399	Wyo. No. 4........	10.25	8.40	.07	81.28	18.44	13,246	7,899	196	710	2,284	52	2,105	59.63	1.48	5.36	17.24	.39	15.90
400	Wyo. No. 5........	9.97	9.25	.04	80.74	19.00	13,222	7,648	308	639	2,453	31	2,143	57.84	2.30	4.83	18.55	.23	16.22
419	.....do..........	6.63	13.23	.08	80.06	28.36	13,471	8,151	284	570	2,791	93	1,632	60.51	1.74	4.23	20.72	.69	12.11
	MISCELLANEOUS.																		
451	Argentine Republic No. 1.........	4.18	16.28	.15	79.44	42.14	12,878	6,597	200	579	4,177	268	1,087	51.01	1.55	4.50	32.45	2.04	8.45
458	.....do..........	5.19	14.45	.26	80.10	33.63	13,279	7,677	410	609	4,159	362	32	57.82	3.09	4.59	31.55	2.72	.24
465	.....do..........	6.54	13.50	.00	79.96	29.61	13,614	8,228	210	673	4,136	0	367	60.44	1.54	4.94	30.38	.00	2.70
172	Brazil No. 1.......	7.41	12.39	.00	80.20	26.12	13,839	8,141	214	584	3,122	0	1,778	58.83	1.55	4.22	22.56	.00	12.84
173	.....do..........	7.43	12.11	.00	80.46	25.47	13,622	8,633	220	583	3,429	0	757	63.38	1.62	4.28	25.17	.00	5.56
	Mixed coals (accurately sized):																		
346	1½ to 3 inches....	10.02	8.94	.16	80.88	19.34	14,263	8,334	296	657	2,641	126	2,210	58.43	2.07	4.61	18.52	.88	15.49
347	1 to 1½ inches....	9.26	9.22	.02	81.50	21.19	14,315	8,508	308	612	2,884	0	2,008	59.43	2.12	4.27	20.15	.00	14.03
351	..	7.94	11.48	.25	80.33	24.03	14,213	8,740	314	624	2,889	246	1,400	61.49	2.21	4.39	20.33	1.73	9.85
362	..	8.22	10.58	.12	81.08	23.42	13,904	8,942	310	584	3,221	115	792	64.04	2.22	4.18	23.07	.82	5.67
366	..	9.28	9.48	.28	80.96	20.77	14,224	8,295	362	601	2,816	237	1,918	58.32	2.54	4.23	19.80	1.67	13.44
370	..	8.94	10.50	.02	80.54	22.10	14,044	8,392	306	588	2,890	0	1,879	59.75	2.17	4.19	20.51	.00	13.38
371	..	6.57	13.42	.06	79.93	29.31	13,923	8,247	340	535	3,531	96	1,174	59.23	2.44	3.84	25.36	.69	8.44
345	Pa. No. 8 dried and Va. No. 4..	10.81	7.64	.21	81.34	19.57	15,354	9,474	43	564	2,666	167	2,438	61.70	.28	3.67	17.38	1.09	15.88
414	Utah No. 1 and R. I. No. 1.....	6.59	12.49	.04	80.88	32.82	14,434	9,029	37	394	4,663	54	267	62.55	.26	2.73	32.31	.37	1.78
415	.....do..........	7.01	12.63	.09	80.27	30.16	14,324	9,551	34	415	4,329	112	—117	66.68	.24	2.90	30.22	.78	—.82
416	Utah No. 2 and R. I. No. 1.....	7.01	12.74	.05	80.20	30.69	13,600	7,436	89	379	3,791	61	1,844	54.68	.66	2.79	27.87	.45	13.56
	Special tests:																		
500	Illinois..........	9.91	9.06	.11	80.92	19.56	14,053	8,788	226	690	3,455	87	798	62.53	1.61	4.97	24.59	.62	5.68
501	.....do..........	9.85	8.41	.07	81.67	19.75	14,294	8,224	226	674	2,972	56	2,138	57.56	1.58	4.72	20.79	.39	14.96
502	.....do..........	8.26	10.50	.04	81.20	28.38	14,257	8,624	249	674	3,608	38	1,064	60.49	1.75	4.73	25.31	.26	7.46
503	.....do..........	9.33	9.62	.07	80.98	20.73	14,248	8,865	256	677	3,259	59	1,132	62.22	1.80	4.75	22.87	.41	7.95
504	.....do..........	8.69	10.45	.00	80.86	22.44	14,281	8,170	187	687	3,673	0	1,564	57.21	1.31	4.81	25.72	.00	10.95
505	.....do..........	10.63	8.07	.10	81.20	18.30	14,276	8,595	248	696	3,153	74	1,510	60.20	1.74	4.87	22.09	.52	10.58
517	.....do..........	8.45	10.69	.06	80.80	23.03	14,341	9,087	199	654	3,068	57	1,276	63.36	1.39	4.56	21.39	.40	8.90
479	Washery refuse....	6.06	13.83	.40	79.71	28.55	13,637	7,784	299	628	3,652	471	803	57.08	2.19	4.61	26.78	3.45	5.89
519	Mixed coke........	12.76	7.49	.03	79.72	18.65	14,339	9,657	113	83	3,330	22	1,134	67.35	.79	.58	23.22	.15	7.91

NOTES ON INDIVIDUAL TESTS.

In these notes the tests are arranged in the order of the States from which the coals came, and under each State in the order of the coal number, as given by the Survey's collectors.

The word "freely," when it refers to the burning of the coal, means that the pieces of coal burned separately without fusing or caking together. The two phrases "coal burned freely" and "coal caked" are used to denote conditions exactly opposite. When the coal ignited easily and burned quickly the notes state that "coal burned quickly."

The length and color of the flame was estimated by the man in charge of the fire. To express the length of the flame in definite terms was difficult, and consequently five expressions having relative value were agreed upon and used. These expressions were: Very short, short, medium, long, and very long. In making any comparison of the different coals on the basis of the length of flame it should be borne in mind that the length of the flame depends not only on the nature of the coal but also on the rate of combustion and on the air supply. With the same coal the higher the rate of combustion the longer the flame. It may be said here that in the same furnace the length of the flame depends on the amount of volatile combustible matter distilled from the coal in a unit time, and on the chemical composition of this volatile combustible matter.

The term "flake sulphur" refers to flakes of calcium sulphate or gypsum.

The expression "furnace door cracked" means that the furnace doors were left slightly open after each firing to admit additional air above the fuel bed so as to reduce the smoke. The expression "automatic air admission operated" refers to the use of the automatic device for admitting air, described on page 20.

These notes also contain statements as to the unreliability of some observations.

The value of coal as a fuel for making steam depends to a great extent on the character of its ash and the behavior of the latter in the furnace. Of two coals otherwise alike the one forming clinkers on the grate is in general of less value than the coal that leaves a free ash. Again, of two coals forming clinkers, the one whose clinker fuses to the grate and is removed with difficulty is of less value than the coal whose clinker does not adhere to the grate. For this reason it is stated in these notes whether the coal formed clinker and whether the clinker was easily removed. The color and the general appearance of the clinker were also noted in the belief that such records might help in the deduction of some useful conclusions.

When trouble from clinker was expected steam was introduced under the grate. Undoubtedly in a large number of cases the steam prevented the clinker from adhering to the grate. Whenever the steam was used under the grate the notes so state. This use of steam should receive proper consideration when studying the clinkering qualities of coals. The quantity of steam thus used was never measured and the heat carried away by superheating this steam to flue-gas temperature was never separately accounted for. This loss is therefore contained in the last item of the heat balance.

ALABAMA.

Test No. 382; No. 2B.—The coal contained large quantities of free slate and considerable dirt, and burned freely. Automatic air admission was not operated. A heavy clinker of reddish-brown color was formed on the grate; it was easily broken up and removed.

Test No. 383; No. 2B.—Automatic air admission was operated. A small amount of reddish brown clinker formed on the grate; it was easily removed.

Test No. 410; No. 2B (large and small briquets).—The briquets held together well in the fire and burned with a long flame; the large briquets were broken in halves. Automatic air admission was not operated. The fire was easily handled. The flue-gas temperature is questionable.

Test No. 390; No. 3.—Thin layers of very bright coal alternated with a dull gray substance. The layers were often irregular, sometimes forming curves much like the grain in a knot of wood. The fracture was very irregular, forming rough surfaces. Free slate occurred in large quantities. The coal burned freely with a long flame. Automatic air admission was not operated. The fire doors were partly open for short intervals after each firing. A thick layer of light porous clinker of light-brown color formed on the grate; it was easily broken and removed. The flue-gas samples are questionable.

Test No. 394; No. 3.—Layers of black coal alternated with layers of a dull substance. The fracture was irregular, forming rough surfaces. Slate was contained in large quantity in thin and thick layers well distributed.

The coal burned slowly with medium length of flame and caked. Automatic air admission was not operated. A thick layer of porous clinker of light-brown color was formed on the grate; it was easily removed. The rated capacity of boiler was difficult to get.

Test No. 375; No. 4.—A considerable quantity of lump slate was present in the coal. Flake sulphur occurred in small quantities. The coal was friable and could be crumbled in the hands; it burned with

a long flame. Steam was used in the ash pit. Automatic air admission was not operated. The furnace doors were cracked after each firing. A thick layer of reddish-brown solid clinker formed on the grate; it was broken up with difficulty and removed in large pieces.

Test No. 376; No. 4.—One-half of the observations of furnace temperature were too low to be read with the Wanner optical pyrometer; moisture in the steam was estimated. The coal burned with a long flame; it caked and required frequent working. Steam was used in the ash pit. Automatic air admission was not operated. The furnace doors were cracked for a short interval after each firing. A light solid clinker of reddish-brown color formed on the grate and was broken up with difficulty.

Test No. 377; No. 4.—The coal burned with a short flame and caked; the fuel bed required considerable attention. Automatic air admission was not operated. A light plastic clinker formed on the grate; it was easily removed. The moisture in the steam was estimated.

Test No. 378; No. 4.—The furnace temperature was too low to be read by the Wanner optical pyrometer. The coal burned rapidly with a long yellow flame and caked; the fuel bed required considerable attention. Automatic air admission was operated. A light porous clinker of brownish color formed on the grate; it was easily removed.

Test No. 413; No. 4 (large and small briquets).—Moisture in the steam was estimated. The briquets held together well in the fire and burned rapidly with a long bright flame; the large briquets were broken in halves before firing. Automatic air admission was not operated. A dark, heavy, plastic clinker formed over the grate; it adhered tightly to the side walls and was removed with some difficulty.

Test No. 478; No. 5.—Coal burned slowly with a short flame, and caked. The fuel bed required considerable attention. Automatic air admission was not operated. A porous brittle clinker of dark-grayish color formed on the grate; it was easily removed.

Test No. 480; No. 5.—The coal burned slowly with a short flame, and the fuel bed required considerable attention. Automatic air admission was not operated. A large amount of brittle porous clinker of dark gray color formed on the grate; it was easily removed. The ash pit was under pressure.

Test No. 484; No. 6.—The coal was partly in layers and partly of crystalline formation; it contained large quantities of slate. The coal burned with a long flame; the volatile matter distilled off quickly. Automatic air admission was not operated. The furnace doors were cracked after each firing. Loose brittle clinker formed on the grate; it was easily removed.

ARKANSAS.

Test No. 293; No. 7A.—The coal burned slowly with a slow flame and caked. Steam was used in the ash pit. Automatic air admission was not operated. The fuel bed required considerable attention. Heavy clinker formed on the grate; it was easily removed.

Test No. 294; No. 7A.—The coal burned slowly with a short flame and caked. Automatic air admission was not operated. A thin layer of heavy, solid clinker formed on the grate; it was removed with difficulty. The ash pit was under pressure.

Test No. 297; No. 8.—The coal contained large quantities of very hard slate; it burned slowly and freely with a short flame. A very hard, solid, nonporous clinker formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 308; No. 8 (washed).—The coal crumbled in the fire and burned slowly with a short flame. Steam was used in the ash pit. Automatic air admission was not operated. A thin layer of very heavy and solid clinker formed on the grate; it was easily removed.

Test. No. 309; No. 8 (washed).—Automatic air admission was not operated. A thin layer of very heavy clinker formed on the grate, impeding the air supply; it was easily removed. Flaming in the stack was noted at intervals.

Test No. 340; No. 10.—The coal burned with a short flame. Automatic air admission was not operated. Free ash, light in weight, formed on the grate. In this test an effort was made to obtain high capacity.

FLORIDA.

Test No. 386; No. 1 (compressed peat).—The peat burned freely and quickly with a very long flame. The briquets did not crumble in fire. Automatic air admission was operated. The fire was easily handled. A small amount of heavy clinker of brownish color formed on the grate; it was easily removed. High capacity was developed. The moisture in the steam was estimated.

GEORGIA.

Test No. 481; No. 1.—The coal burned freely and rapidly with a long flame. Automatic air admission was not operated. A large amount of loose clinker formed on the grate; it was quickly removed.

ILLINOIS.

Test No. 106; No. 6B (washed).—The coal burned quickly with a long flame and caked. The fuel bed required much attention,

Heavy clinker of dark-brown color formed on the grate, but was easily removed. Molten refuse dropped into the ash pit. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 313; No. 6B (briquets).—The briquets held their shape well in the fire and burned with a long flame; they were broken in half before firing. A very light and porous clinker formed on the grate; it was easily removed. Automatic air admission was operated. The test was too short for reliable results.

Test No. 314; No. 6B (briquets).—The briquets burned with a long flame; they were broken in halves before firing. A hard, solid clinker formed in a thick layer over the grate; it was easily removed. Automatic air admission was not operated. The test was too short for reliable results.

Test No. 122; No. 7C.—The coal burned slowly with a short white flame and caked badly. The fuel bed required much attention. A heavy clinker of dark-brown color formed on the grate; it was easily removed. Steam was used in the ash pit. Automatic air admission was not operated.

Test No. 129; No. 7C (washed).—The coal burned slowly and caked. Heavy clinker of dark-gray color and free ash formed on the grate. The fires were easily cleaned. The furnace doors were cracked for one minute after each firing. Automatic air admission was not operated.

Test No. 142; No. 7D.—The coal burned rapidly with a yellow flame and caked. Automatic air admission was operated. Clinker formed in a heavy mass over the entire grate; it was easily removed. The free ash was gray in color.

Test No. 143; No. 7D.—The coal burned rapidly with a yellow flame and caked. The clinker was of a dark-red color, heavy and blistery in appearance; it was easily removed from the grate on which it formed in a compact bed. Automatic air admission was operated.

Test No. 146; No. 7D.—The coal burned slowly. Very heavy clinker of dark-brown color formed in a layer over the grate. Automatic air admission was operated.

Test No. 516; No. 7E.—The coal burned with a short flame. Automatic air admission was not operated. A large amount of clinker formed on the grate; it was easily removed. The ash pit was under pressure.

Test No. 101; No. 8.—The fuel bed required much attention. Clinker matted on the grate. The conditions of the test were

unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 102; No. 8.—The coal burned freely with a long flame; the fuel bed required much attention. Dark and heavy clinker formed on the grate; it was easily removed. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 103; No. 9A.—The coal burned very freely with a long flame. The clinker was easily removed from the grate. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 104; No. 9A.—The coal burned very freely with a long flame. The fire required much attention. A dark and heavy clinker formed on the grate; it was easily removed. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 105; No. 9A.—The coal burned freely with a long flame. Dark and heavy clinker formed on the grate; it was easily removed. Molten refuse dropped into the ash pit. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 113, No. 9A (washed).—The coal burned rapidly with a long flame and caked; the fuel bed required much attention. A heavy clinker of brown color formed on the grate; it was easily removed. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 121; No. 9B.—The coal burned very rapidly and caked; the fuel bed required much attention. Molten refuse dropped into the ash-pit. Soft heavy clinker of dark color formed over the grate; it was easily removed. Automatic air admission was not operated.

Test No. 492; No. 9C (briquets).—Automatic air admission was not operated. The fuel bed required considerable attention. A large amount of clinker formed on the grate; it was easily removed. The ash pit was kept under pressure.

Test No. 107; No. 10.—The coal burned rapidly and caked; the fuel bed required much attention. The clinker was heavy and of brown color, but was easily removed from the grate. A little steam was used in the ash pit. The conditions of the test were unfavorable;

a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 108; No. 10.—The coal burned rapidly and caked; the fuel bed required much attention. The clinker was heavy and of brown color, but was easily removed from the grate. Steam was used in the ash pit. There was not much smoke in the forenoon but there was considerable in the afternoon. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 109; No. 10.—The coal burned rapidly and caked; the fuel bed required much attention. The clinker was brown and heavy, but was easily removed from the grate. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 110; No. 10.—The coal burned very rapidly and caked; the fuel bed required much attention. A dark-brown clinker fused to the grate. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 114; No. 10 (washed).—The coal burned rapidly and caked; the fuel bed required much attention. The furnace was much hotter at the end of the test than at the start. The clinker was dark and heavy; it was easily removed from the grate. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 137; No. 11A.—A layer of clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 138; No. 11A.—The coal burned slowly. Heavy clinker of brown color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 139; No. 11A.—A layer of clinker formed on the grate; it was removed easily. Automatic air admission was operated.

Test No. 141; No. 11A.—The coal burned slowly. Heavy clinker of dark brown color formed on the grate; it was easily removed. The free ash was gray in color. Automatic air admission was operated.

Test No. 111; No. 11B.—The coal burned rapidly and caked; the fuel bed required much attention. Heavy clinker of brown color adhered to the grate. Molten refuse dropped into the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 112; No. 11B.—The coal burned rapidly and caked; the fuel bed required much attention. Heavy clinker of brown color

adhered to the grate and was difficult to remove. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 115; No. 11B.—The coal burned rapidly and caked; the fuel bed required much attention. Heavy clinker of brown color formed on the grate; it was easily removed. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 116; No. 11B.—The coal burned rapidly and caked; the fuel bed required much attention. Heavy clinker of brown color formed on the grate; it was easily removed. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 117; No. 11B.—The coal burned rapidly and caked; the fuel bed required much attention. Heavy clinker of brown color formed on the grate; it was easily removed. Molten refuse dropped into the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Steam was used in the ash pit. Automatic air admission was not operated.

Test No. 118; No. 11B.—The coal burned rapidly and caked; the fuel bed required much attention. Heavy clinker of brown color formed on the grate; it was easily removed. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated.

Test No. 119; No. 11B.—The coal burned rapidly and caked. Molten refuse dropped into the ash pit. Heavy clinker of dark-brown color formed on the grate; it was easily removed. Steam was used in the ash pit. The conditions of the test were unfavorable; a better evaporation should have obtained. Automatic air admission was not operated.

Test 120; No. 11C.—The coal burned rapidly and caked; the fuel bed required much attention. A thin layer of tough heavy clinker of dark color formed over the entire grate; it was easily removed. The conditions of the test were unfavorable; a better evaporation should have been obtained. Automatic air admission was not operated. The coal was washed at the mine.

Test No. 312; No. 11C (briquets).—The briquets were broken in halves before firing and burned freely; the volatile matter distilled slowly. Automatic air admission was operated one minute after

firing. A light porous clinker formed on the grate; it was easily removed. The test was too short for reliable results. The coal was washed at the mine.

Test No. 127; No. 12.—The coal burned very rapidly and caked somewhat. The clinker was brown in color and heavy. Large pieces of free ash light in color formed on the grate. The fire doors were cracked for one minute after each firing. Automatic air admission was not operated.

Test No 128; No. 12.—The fire was easily cleaned. The fuel bed required little attention. During the entire test the stack damper was closed during firings. Automatic air admission was not operated.

Test No. 131; No. 12.—The coal burned slowly with a yellow flame. The clinker was brown and heavy; it was easily removed from the grate. The free ash was light gray in color. Automatic air admission was not operated.

Test No. 133; No. 12.—The clinker was easily removed from the grate. Automatic air admission was not operated.

Test No. 135; No. 12 (washed).—The coal burned freely. Clinker formed in a thin layer on the grate, but was easily removed. The test was run for maximum capacity. Automatic air admission was operated.

Test No. 136; No. 12.—The coal burned slowly with a short yellow flame. Molten refuse dropped into the ash pit. Clinker formed on the grate, but was easily removed. Automatic air admission was operated.

Test No. 463; No. 12B (briquets).—The briquets burned slowly with a short flame. Steam was used in the ash pit. A thin brown clinker formed on the grate; it was easily removed. Forced draft was used one-half hour before cleaning.

Test No. 132; No. 13.—The coal burned freely. Molten refuse dropped into the ash pit. Heavy clinker of brown color formed in a thin layer over the grate, but was easily removed. The ash was light in weight and color. The fire doors were cracked for one minute after each firing. Automatic air admission was not operated.

Test No. 134; No. 13.—The clinker was easily removed from the grate. Automatic air admission was not operated.

Test No. 144; No. 13 (washed).—The coal burned freely and the fire was easily handled. Large pieces of free ash light in color formed on the grate. The clinker was porous and light in weight. Automatic air admission was operated.

Test No. 145; No. 13 (washed).—The coal burned freely. A little porous clinker, light in color, and free ash formed on the grate. Automatic air admission was operated.

Test No. 123; No. 14.—The coal burned freely. Molten refuse dropped into the ash pit. Clinker of dark-gray color formed in a thin layer on the grate and was easily removed. Automatic air admission was not operated.

Test No. 125; No. 14.—The coal burned rapidly and caked. Molten refuse dropped into the ash pit. Heavy clinker of a brown color formed in a thin layer on the grate; it was easily removed. The free ash was of a light-gray color. The fire doors were cracked after each firing. Automatic air admission was not operated.

Test No. 130; No. 14 (Washed).—The coal burned freely. The free ash was of a light color and light in weight. A thin layer of brown clinker formed on the grate; it was easily removed. Steam was used in the ash pit. The doors were cracked for one minute after each firing. Automatic air admission was not operated.

Test No. 126; No. 15.—The coal burned rapidly and caked. Large pieces of free ash, light gray in color, formed on the grate. The fire was easily cleaned. The clinker was brown and heavy. The fire doors were cracked for one minute after each firing. Automatic air admission was not operated.

Test No. 152; No. 15 (Washed).—Sulphur occurred in the coal in thin layers, and gypsum and calcite were present in thin transparent flakes. The coal burned rapidly and caked. The clinker was removed with difficulty. Automatic air admission was operated.

Test No. 150; No. 16.—Gypsum and calcite occurred in the coal in thin opaque layers. Slate of a dark-gray color was present in small quantities detached from the coal. The coal burned rapidly and caked somewhat. A porous clinker, light in weight, and of a dark-gray color, formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 140; No. 18.—The coal burned slowly. The clinker fused to the grate and was removed with difficulty. Automatic air admission was operated.

Test No. 148; No. 18.—The coal contained sulphur in thick, ramifying layers; gypsum and calcite occurred in thick opaque flakes; there was also a little slate of a dark-gray color. The coal burned freely; cracked after firing and crumbled. Very heavy clinker of dark-brown color formed a thin layer over the grate; it was easily removed. Automatic air admission was operated. Steam was used in the ash pit.

Test No. 147; No. 18 (washed).—The coal burned freely and cracked in the fire. Heavy clinker of brown color formed a thin solid layer over the grate; it was removed with difficulty. Automatic air admission was operated.

Test No. 149; No. 18 (washed).—The coal burned freely and cracked after firing. Heavy clinker of a dark-brown color formed a thin layer over the grate; it was easily removed. Automatic air admission was operated. Steam was used in the ash pit.

Test No. 160; No. 19A.—Heavy clinker of brown color formed a thin layer over the grate; it was easily removed. Automatic air admission was operated.

Test No. 161; No. 19A.—The coal burned slowly The clinker was heavy and brown in color; it was easily removed from the grate. Automatic air admission was operated.

Test No. 163; No. 19A.—The coal burned with a short flame, and caked; the fuel bed required much attention. The clinker was light and brittle; it was easily removed from the grate. Automatic air admission was operated.

Test No. 170; No. 19A.—The coal caked in the fire. A thin layer of light white clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 171; No. 19A.—The coal caked in the fire. The clinker was light in weight and color; it was easily removed from the grate. Automatic air admission was operated.

Test No. 175; No. 19B.—Gypsum and calcite occurred in the coal in opaque flakes. A small quantity of slate adhered to the coal. The coal burned freely with a long flame and cracked in the fire. Large pieces of light, white, free ash formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 204; No. 19B.—Gypsum and calcite occurred in the coal in small quantities in opaque flakes. A small quantity of slate adhered to the coal, with an occasional free piece. The coal burned freely. A very light, porous clinker, light in color, and free ash formed on the grate. The fire was easily handled. Automatic air admission was operated.

Test No. 205; No. 19B.—The coal burned freely. A light porous clinker, light in color, and free ash formed on the grate. The fire was easily handled. Automatic air admission was operated.

Test No. 420; No. 19C.—The coal contained a large quantity of free slate. Some slate adhered to the coal. Gypsum occurred in small opaque flakes. The coal burned quickly and freely with a medium length flame. Automatic air admission was operated. The fire doors were cracked after each firing. A thick porous clinker formed on the grate; it was easily broken and removed from the furnace.

Test No. 423; No. 19C.—Automatic air admission was used in the forenoon. A light-brown clinker formed on the grate.

Test No. 424; No. 19D.—The coal contained a large amount of slate, both free and attached, a little sulphur, and a large amount of gypsum. It burned freely and quickly, with a long, light flame. Automatic air admission was operated. The fire doors were cracked after each firing. The test was run for economy. A large quantity of clinker of light-gray color formed on the grate; it was easily removed.

Test No. 425; No. 19D.—The coal burned freely and quickly with a long, bright flame. Automatic air admission was operated. The fire doors were cracked after each firing. A thick layer of brittle clinker formed on the grate; it hindered the rate of combustion, but was easily removed.

Test No. 421; No. 19E.—The coal contained a considerable quantity of free slate; it burned quickly with a long flame, and caked. Automatic air admission was operated. The fire doors were cracked after each firing. A layer of tough clinker and free ash of light-gray color formed on the grate.

Test No. 422; No. 19E.—The coal burned with a short flame. Automatic air admission was operated. Light-brown clinker formed on the grate; it was easily removed. The test was run for maximum capacity.

Test No. 292; No. 20.—The coal contained a large quantity of free slate, and also a small quantity of sulphur in thin layers. It burned with a long yellow, flame; the fuel bed required considerable attention. A dark-gray clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 301; No. 20 (washed).—The coal burned freely. A thin layer of porous clinker formed over the grate; it was easily removed. Automatic air admission was not operated.

Test No. 302; No. 20 (washed).—The coal burned freely. Automatic air admission was not operated. The fire was easily handled.

Test No. 315; No. 21.—Some pieces of coal contained large quantities of sulphur; gypsum and calcite were rather prevalent. "Soapstone" was present in large pieces; also slate in thick layers. The coal burned freely with a long flame. A thick porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 316; No. 21.—Free slate occurred in large quantities. Calcite and gypsum were present in small opaque flakes. The coal burned freely with a long flame, and cracked in the fire. Automatic air admission was operated. A layer of solid clinker formed on the grate; it was easily removed.

Test No. 318; No. 21 (briquets).—The briquets burned freely with a tendency to crumble; they were broken in half before firing. Dark

heavy clinker formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 324; No. 22A.—Layers of black shiny coal alternated with layers of a dull-gray substance. The coal fractured in planes parallel and at right angles to the layers and was of medium hardness. Sulphur in large balls occurred in large quantities, as thick layers and thin veins, distributed through the coal. Slate occurred in large quantities, adhering to the coal in both thick and thin layers. Large quantities of gypsum and calcite occurred in thin white flakes. The coal burned freely and quickly, with a long flame. A thick layer of porous, heavy, and plastic clinker formed on the grate; it was easily removed. The fire was easily handled. Automatic air admission was operated.

Test No. 325; No. 22A.—Thin layers of bright black coal alternated with thin layers of a dull gray substance. The coal fractured in planes parallel and at right angles to the layers, and was of medium hardness. Sulphur occurred in large quantities in large balls, thick layers and thin veins well distributed through the coal. There was much slate in thick layers adhering to the coal. Gypsum and calcite occurred in large quantities in thin white flakes. The coal burned freely and quickly, with a long, yellow flame. Automatic air admission was operated. A thick layer of heavy, porous clinker of dark-brown color formed on the grate; it was easily removed. The rated capacity of the boiler was rather difficult to obtain with this coal.

Test No. 328; No. 22A (washed).—The coal burned freely with a long flame. Steam was used in the ash pit after cleaning the fire. Automatic air admission was operated. A very light and porous clinker formed over the grate; it was easily removed. This test was run for maximum capacity.

Test No. 306; No. 23A.—The coal burned freely with a long flame. The clinker was soft and porous. Steam was used in the ash pit. Automatic air admission was operated. The fire was easily handled.

Test No. 317; No. 23A (washed).—Thin layers of slate and very thin layers of sulphur were found in pieces of the coal. Thin layers of black shiny coal alternated with a dull brown substance. The coal was rather soft but not brittle; it burned freely with a long flame. A layer of heavy, solid, plastic clinker formed on the grate, and was broken with difficulty. Automatic air admission was operated.

Test No. 321; No. 23B (briquets).—The briquets burned freely and quickly with a long white flame, and did not crumble; they were broken in halves before firing. Automatic air admission was operated. The furnace doors were cracked after each firing. The test was too short for reliable results.

Test No. 322; No. 23B (briquets).—The briquets burned quickly with a long flame; they were broken in halves before firing. The test was too short for reliable results. The furnace doors were cracked after each firing. Automatic air admission was not operated. A thick layer of porous clinker formed on the grate; it was easily removed.

Test No. 335; No. 24B.—Sulphur occurred in large balls and in thick layers adhering to the coal. Slate was present in small quantities in thin and thick layers easily separated from the coal. Gypsum and calcite occurred in small quantities in thin flakes. The coal fractured at right angles and in planes parallel to the layers, and was of medium hardness. Thin layers of black shiny coal alternated with layers of a dark gray substance. The coal burned freely and with a long flame. Automatic air admission was operated. Steam was used in the ash pit. A thick layer of solid, heavy clinker formed on the grate; it was easily removed.

Test No. 336; No. 24B.—The coal burned quickly with a long, yellow flame, and caked. Automatic air admission was operated. A layer of solid, heavy clinker, dark brown in color, formed on the grate; it was easily removed.

Test No. 337; No. 24B.—The coal burned freely and quickly and with a long flame. Automatic air admission was operated. A thick layer of solid, heavy clinker, dark brown in color, formed on the grate; it was easily removed. The test was too short for reliable results.

Test No. 338; Nos. 25A and 25B.—A large quantity of sulphur was present in thick layers. Large pieces of free slate were somewhat prevalent. Gypsum and calcite were present to a considerable extent. The coal burned freely, with a long flame. Automatic air admission was operated. A light and porous clinker, dark brown in color, formed on the grate; it was easily removed. The test was run for maximum capacity.

Test No. 339; Nos. 25A and 25B.—The coal burned freely, with a long flame. Automatic air admission was operated. A very fragile but solid clinker formed on the grate; it was easily removed.

Test No. 341; No. 26.—A small quantity of sulphur was present in the coal, as balls and flakes; small quantities of slate, gypsum, and calcite were also present. The coal burned freely, with a long flame. The clinker was hard and heavy, impeding the air supply; it was removed with difficulty. Automatic air admission was not operated.

Test No. 342; No. 26.—The coal burned with a long flame. Heavy clinkers formed a compact layer on the grate. Steam was used in

the ash pit. Automatic air admission was not operated. It was necessary to wet the ash and refuse in the ash pit so as to prevent the clinker from fusing on the grate.

Test No. 353; No. 27.—Layers of a bright black substance alternated with layers of dull coal; it fractured at right angles and parallel to the layers, and was rather hard. Sulphur occurred as iron pyrites in flakes and balls. A small quantity of slate was present in thick layers. Gypsum and calcite were present in thin flakes. Some finely divided clay was present. The coal burned with a long flame. Steam was used in the ash pit. A thick layer of solid, heavy clinker formed on the grate; it was easily broken and removed. Automatic air admission was not operated.

Test No. 354; No. 27.—The coal burned freely. The clinker was heavy and of an iron-red color; it was a serious impediment to the air supply, but was easily removed from the furnace. Two vanes of the automatic air admission were operated continuously.

Test No. 459; No. 28A (washed briquets).—The briquets burned with a short flame. A part of the large briquets were broken before firing. Automatic air admission was not operated. When the large briquets were burned, heavy clinker formed on the grate, impeding the air supply. The small briquets gave better results. The coal was washed at the mine.

Test No. 457; No. 28B (briquets).—The large briquets were fired both whole and broken in halves; they burned quickly. The small briquets were badly broken up. A thick, solid clinker formed on the grate, but was easily removed. The grate was in poor condition, and the fire was sliced with difficulty.

Test No. 448; No. 28C.—The coal burned freely and rapidly. Automatic air admission was operated. A large amount of clinker formed on the grate; it was easily removed.

Test No. 452; No. 28C.—The coal burned freely, with a long flame. Two vanes of the automatic air admission were operated. The middle furnace door was cracked after each firing. Clinker and ash formed on the grate; they were easily removed.

Test No. 465; No. 29A (washed briquets).—The briquets burned with a medium length flame. Steam was used in the ash pit during the last half of the test. Automatic air admission was not operated. A thin, black, plastic clinker adhered to the side walls at the first cleaning; at the second cleaning the clinker was brittle and easily removed from the furnace, owing to use of steam in the ash pit.

Test No. 460; No. 29B.—The coal contained a small amount of gypsum, iron pyrites, and slate; it burned quickly, with a medium length flame. Automatic air admission was operated. A gray clinker formed on the grate; it was easily removed.

Test No. 461; No. 29B.—The coal burned quickly, with a medium length flame. Automatic air admission was operated. A gray clinker formed on the grate; it was easily removed.

Test No. 466; No. 29B (briquets).—The briquets burned with a medium length flame. Steam was used in the ash pit. Automatic air admission was not operated. A black porous clinker fused to the side walls; it was easily broken and removed.

Test No. 511; No. 30 (washed briquets).—Automatic air admission was not operated. The fuel bed required much attention. The clinker was easily removed.

Test No. 489; No. 31 (briquets).—The briquets burned with a long flame. Automatic air admission was not operated. A brittle porous clinker of dark gray color formed on the grate; it was easily removed.

Test No. 491; No. 31 (briquets).—Automatic air admission was not operated. A large amount of clinker formed on the grate; it was easily removed.

Test No. 513; No. 33 (briquets).—The coal burned with a short flame. Automatic air admission was not operated. The fuel bed required much attention. A large quantity of clinker formed on the grate; it was easily removed.

Test No. 509; No. 34B.—Steam was used in the ash pit. The furnace doors were cracked after each firing. Automatic air admission was not operated. Coal caked on account of the clinker impeding the air supply. The fire was easily handled.

INDIANA.

Test No. 163; No. 3.—Sulphur occurred in the coal in large balls and in thick layers. Slate occurred in large pieces and in large quantity, separated from the coal. The coal burned with a long flame. The clinker, dark in color and heavy, was easily removed from the grate. Automatic air admission was operated.

Test No. 151; No. 4.—Gypsum and calcite occurred in the coal in thin opaque flakes; a large quantity of free slate was present. Coal burned slowly and did not break up in the fire. The clinker was light in weight and porous. Large pieces of free ash formed on the grate. The fire was easily cleaned. Automatic air admission was operated.

Test No. 165; No. 4.—Gypsum and calcite occurred in the coal in thin, opaque flakes; a large quantity of free slate was present. A small quantity of clay was visible. The coal caked in the fire. Light, porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 166; No. 4.—A thick, blistery, dark brown and heavy clinker formed over the grate; it was easily removed. Automatic air admission was operated.

Test No. 154; No. 4 (washed).—Gypsum and calcite occurred in the coal in very small quantities in thin, opaque flakes. The coal burned rapidly and caked. The fire was easily cleaned. Automatic air admission was operated.

Test No. 153; No. 5.—Sulphur occurred in the coal in large balls; gypsum and calcite occurred in small quantities in thin, transparent flakes. A small amount of free slate was present. The coal burned rapidly and caked. The fuel bed required much attention. The clinker was dark in color and very heavy; it was easily removed from the grate. Molten refuse dropped into the ash pit. Automatic air admission was operated.

Test No. 155; No. 5.—Sulphur occurred in the coal in large balls and thick layers; gypsum and calcite occurred in thin, small, transparent flakes, and a small quantity of free slate was present. The coal burned slowly and caked. The fuel bed required much attention. The clinker was brown in color and heavy; it was easily removed. Automatic air admission was operated.

Test No. 156; No. 5.—Sulphur occurred in the coal in large balls and thick layers; gypsum and calcite occurred in thin, small, transparent flakes. A small quantity of free slate was present. The coal burned slowly and caked. The clinker was dark brown in color and heavy; it was easily removed. Automatic air admission was operated.

Test No. 157; No. 6.—Sulphur occurred in thick layers; gypsum and calcite occurred in thin, transparent flakes; a few thick layers of bone coal were present. A small quantity of free slate was visible. The coal burned slowly and caked. The clinker was dark brown in color; it was heavy but easily removed from the grate. Automatic air admission was operated.

Test No. 159; No. 6 (washed).—The coal burned very rapidly and caked in the fire. The clinker was of a brown color; it was easily removed from the grate. Automatic air admission was operated.

Test No. 158; No. 7A.—Sulphur occurred in the coal in thick layers; gypsum and calcite were present in thick, transparent flakes. A small quantity of free slate was visible. The coal burned rapidly and caked in the fire. The clinker was light in weight, porous, and of a dark-gray color; no difficulty was experienced in removing it from the grate. Automatic air admission was operated.

Test No. 288; No. 7A (briquets).—The briquets burned freely and did not crumble in the fire; they were broken in halves before firing. Automatic air admission was operated. A solid, heavy clinker formed on the grate. In the first cleaning it was removed with diffi-

culty; in the second cleaning it could not be removed. A light vapor was visible at the top of the stack during the entire test.

Test No. 164; No. 7B.—The coal burned with a long, yellow flame, and caked in the fire. The fuel bed required much attention. The clinker was of dark-red color and heavy; it was fused to the grate and was removed with difficulty. Automatic air admission was operated after the first hour.

Test No. 176; No. 7B.—Gypsum and calcite occurred in the coal in thin, opaque flakes; very little sulphur was discernible. The coal burned freely when screenings of the largest size were fired; it burned with a long flame. A very thin layer of heavy dark clinker clung tightly to the grate. Automatic air admission was operated.

Test No. 182; No. 8.—Sulphur occurred in the coal in a small quantity in thin layers; gypsum and calcite were present in a small quantity in thick, transparent flakes. Slate occurred in a small quantity in thin layers, adhering to the coal. The coal burned with a long, yellow flame. A light, porous clinker of dark color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 183; No. 8.—Sulphur was somewhat prevalent in the coal both in flakes and balls; gypsum and calcite were present in small quantity in opaque flakes. All lump coal contained much shale. The coal burned with a long, yellow flame, and caked. Clinker of medium weight and a dark-red color formed on the grate in a porous layer; it was easily removed. Automatic air admission was operated.

Test No. 185; No. 8.—Light clinker of a dark-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 184; No. 8 (washed).—The coal burned freely. Light porous clinker and free ash of a dark-gray color formed on the grate; the clinker was easily removed. Automatic air admission was operated.

Test No. 168; No. 9A.—Much sulphur occurred in the coal in large balls and thick layers. Gypsum and calcite were present in small quantity in thin, transparent flakes. A small quantity of free slate was visible. The coal burned rapidly and caked in the fire. Light porous clinker and free ash formed on the grate. The fire was easily handled. Automatic air admission was operated.

Test No. 169; No. 9A.—The coal burned with a long, yellow flame. The clinker was of purple blue color and heavy; it contained much slate and was easily removed from the grate. The free ash was of a dark-gray color. Automatic air admission was operated.

Test No. 174; No. 9B.—The coal burned with a long yellow flame, and caked. A light porous clinker of dark-brown color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 334; Nos. 9A and 9B (briquets).—The briquets burned freely and quickly, with a long flame, and did not crumble; they were broken in halves before firing. Automatic air admission was operated. A thick layer of porous and plastic clinker formed on the grate; it was easily removed. The test was too short for reliable results.

Test No. 167; No. 10.—Sulphur occurred in the coal in small quantity, in thick layers; gypsum and calcite occurred in thin, somewhat transparent flakes. A small quantity of slate adhered to the coal. The coal burned rapidly and caked. The clinker was easily removed from the grate. Automatic air admission was operated.

Test No. 177; No. 10 (washed).—Sulphur occurred in thin yellow layers at right angles to the coal stratum; gypsum and calcite were present in thin white flakes. Considerable clay was spread in thin layers over all the surfaces of the coal. A large quantity of shale was visible. The coal burned freely. A thin layer of heavy clinker of dark-red color formed over the grate; it was easily removed. Automatic air admission was operated.

Test No. 233; No. 11.—The coal contained a small quantity of flake sulphur. A large quantity of both free and attached slate was present. The coal burned freely, with a long flame. The volatile matter distilled very rapidly. A light porous clinker of dark-red color formed on the grate; it was easily removed. The free ash was light in weight and color. Automatic air admission was operated.

Test No. 234; No. 11.—Layers of bright coal alternated with a dull gray substance; it fractured irregularly. The coal burned freely and with a long yellow flame. A layer of light porous clinker of a gray color was formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 235; No. 11.—The coal burned with a long flame; the fine coal caked in the fire. The volatile matter distilled slowly. Free ash, light in weight and color, and a thin, porous layer of clinker of dark-brown color, formed over the grate; it was easily removed owing to the presence of slate. Automatic air admission was operated.

Test No. 299; No. 12.—The coal contained a large quantity of sulphur, present in balls. Considerable black slate was visible. Hardened white clay was spread over the coal. The coal burned very quickly, with a long flame, and caked. A very fragile and porous clinker formed on the grate; it was easily removed. Automatic air admission was not operated. The furnace doors were cracked after each firing for about one and one-half minutes. The combustion wall was down during this test.

Test No. 300; No. 12.—Sulphur occurred in the coal in thick layers and large balls. The coal burned freely, with a long yellow flame. A

thick porous clinker formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 310; No. 12 (washed).—The coal burned freely, with a long yellow flame. Automatic air admission was operated. A light porous clinker and free ash formed on the grate. Flue gas temperature readings were about 150° too low.

Test No. 432; No. 13.—The coal cracked in the fire and burned freely with a bright yellow flame. Automatic air admission was operated. The fire was easily handled. Heavy clinker formed on the grate; it was easily removed. Intense combustion occurred during the firing intervals. The test was run to obtain high capacity.

Test No. 433; No. 13.—Automatic air admission was operated. The test was too short for reliable results.

Test No. 430; No. 14.—The coal was easily broken. Many layers of slate and iron occurred in the pieces of coal. Large amounts of sulphur and gypsum were present. The coal burned slowly on account of the large amount of clinker. Steam was used in the ash pit during the last half of the day. Molten refuse dropped into the ash pit. A tough, porous and heavy clinker of bluish-gray color adhered tightly to the grate and was removed with difficulty.

Test No. 431; No. 14.—A steam blower was used in the ash pit successfully to prevent clinker sticking to the grate. Automatic air admission was operated. A dark, heavy, solid clinker formed on the grate; it was easily removed.

Test No. 428; No. 15.—The coal burned freely and rapidly. Automatic air admission was operated. A large amount of loose, brittle clinker of light-gray color formed on the grate; it was easily removed. The test was run to obtain high capacity.

Test No. 429; No. 15.—Automatic air admission was operated. The fire was easily handled. Test was run to obtain high capacity.

Test No. 426; No. 16.—Automatic air admission was operated. Fire was easily handled.

Test No. 427; No. 16.—The test was run to obtain high capacity, but large amounts of fine coal prevented success. The fire was easily handled. Automatic air admission was operated.

Test No. 441; No. 17.—Automatic air admission was operated. A solid clinker formed on the grate impeding the air supply; it was easily removed.

Test No. 442; No. 17.—A solid clinker adhered to the grate, impeding the air supply; it was removed with some difficulty. Automatic air admission was operated. The combustion chamber temperature was higher at the close of the test than at the start.

Test No. 435; No. 18B.—In fracture the coal resembled pitch. A small amount of gypsum was present; iron pyrites were very preva-

lent. The coal burned rapidly, with a long, yellow flame, and caked. Automatic air admission was operated. When the coal was fired, the fine coal flashed like powder. A light and porous clinker of brownish color formed on the grate; it was broken up with difficulty, but easily removed.

Test No. 436; No. 18B.—The coal burned quickly, with a long yellow flame, and caked. When thrown in the furnace, the fine coal flashed into flame. A layer of very porous and plastic clinker formed on the grate and adhered to the side walls; it was broken up with difficulty.

Test No. 464; No. 19 (briquets).—The briquets burned with a short flame. Automatic air admission was not operated. The clinker was easily removed.

INDIAN TERRITORY.

Test No. 417; No. 2B.—The coal burned freely. The fire doors were cracked after each firing. Automatic air admission was operated. A heavy, porous clinker formed on the grate; it was easily removed.

Test No. 418; No. 2B.—The coal burned freely with a long flame and the volatile matter was distilled off quickly. The clinker did not impede the air supply. The test was made to obtain high capacity. Moisture in the steam was estimated.

Test No. 455; No. 2B (briquets).—The fuel bed required considerable attention. The large briquets burned slowly and the small briquets quickly. A thin, tough, solid clinker of purple color adhered to the grate, impeding the air supply; it was removed with difficulty. Water was used in the ash pit. Automatic air admission was operated during part of the test.

Test No. 453; No. 2B (briquets).—Both natural and forced draft were used. The briquets burned quickly with medium length flame. Molten refuse dropped into the ash pit. Automatic air admission was operated for two hours. In the first cleaning a thin, solid clinker of dark-gray color stuck to the grate; it was removed with difficulty. After cleaning, 200 pounds of limestone was spread over the grate. The second cleaning was as difficult as the first.

Test No. 456; No. 2B (washed briquets).—The briquets were fired whole part of the time and part of the time broken in halves. They burned quickly, the unbroken briquets giving the better results. Water was used in the ash pit. A thin, tough, solid clinker of purple color adhered to the grate, impeding the air supply; it was removed with difficulty.

Test No. 437; No. 8 (washed briquets).—The briquets burned rapidly with a short flame and did not crumble in the fire. Automatic air admission was operated. Molten refuse dropped into the ash pit.

A thin layer of very heavy clinker of grayish color adhered to the grate and was removed with difficulty. Part of the combustion wall fell during this test.

Test No. 449; No. 9.—The coal burned with a short flame. Automatic air admission was not operated. The clinker adhered to the grate. In the first cleaning loose clinker was formed on the grate; it was easily removed. In the second cleaning light clinker adhered to the grate and was removed with difficulty.

Test No. 450; No. 9 (briquets).—The briquets burned with a short flame. Automatic air admission was not operated. One hundred and nineteen pounds of limestone was spread over the grate at the end of the first cleaning. In the first cleaning the clinker was easily removed from the grate, but adhered a little to the side wall. In the second cleaning, a light tough clinker adhered to the grate and was removed with difficulty.

JAMESTOWN.[a]

Test No. 601; No. 1.—The coal had a dull color resembling slate and was broken with difficulty. It contained large quantities of calcite and gypsum and a small amount of slate and dirt. The coal burned with a medium length flame and caked. A porous clinker formed on the dead plate and adhered to the bridge wall.

Test No. 602; No. 1.—The coal had a dull color resembling slate, and it was broken with difficulty. It contained large quantities of calcite and gypsum and a small amount of slate and dirt. The coal burned with a medium length flame and caked. A small porous clinker formed on the dead plate and adhered to the bridge wall.

Test No. 603; No. 3.—The coal appeared very black and had a luster similar to anthracite. It was very friable and contained small amounts of dirt, dust, sulphur, calcite, and gypsum. A large amount of slate was visible. The coal burned with a short flame. A hard, porous clinker formed on the dead plate.

Test No. 604; No. 3.—The coal burned with a short flame. A hard, porous clinker formed on the dead plate.

Test No. 605; No. 3.—The coal burned rapidly with a short flame. A very porous clinker of reddish-brown color formed on the dead plate. The load was very variable on the test.

Test No. 606; No. 3.—The fuel bed required considerable attention. During part of the test the furnace doors were cracked after firing.

Test No. 607; No. 3.—The coal burned with a short flame and caked. The fuel bed required considerable attention. The volatile matter distilled off quickly. A brittle clinker of reddish-brown color formed on the grate and adhered to the side walls. Automatic air admission was operated continuously. The moisture in the steam was estimated.

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[a] Coals from Virginia and West Virginia.

Test No. 608; No. 4.—The coal was very black; fresh surfaces had a luster resembling anthracite. The coal was broken with difficulty. It contained a small amount of slate, sulphur, gypsum, and calcite; also some bone coal. It burned slowly with a medium length flame and caked. The fuel bed required considerable attention. A layer of heavy, compact clinker of reddish-brown color adhered to the grate; it was removed with much difficulty. Automatic air admission was partly open continuously. The moisture in the steam was estimated.

Test No. 609; No. 4.—The test was too short for reliable results. The coal burned rapidly with a short flame and caked. Two hundred and three pounds of limestone was spread over the grate at the start of the test. The fuel bed required considerable attention. A reddish compact clinker, easily broken and removed, formed over the grate. Automatic air admission was not operated. No flue-gas analysis was made on this test. The figure given for the weight of the ash and refuse includes the remains of the limestone.

Test No. 610; No. 4.—The coal burned rapidly with a short flame and caked. The fuel bed required considerable attention. A very compact clinker of reddish color formed on the grate and was broken up with some difficulty. It did not adhere to the grate, owing to the presence of water in the ash pit. Automatic air admission was not operated. One thousand three hundred and eighty pounds of water were used in the ash pit to cool the grate. This water was not considered in figuring the heat balance. A calculation shows that the water caused a heat loss of 1.19 per cent based on the combustible.

Test No. 611; No. 4.—The coal burned with a medium length flame and caked. The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter.

Test No. 612; No. 4.—The coal burned with a medium length flame and caked. The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter.

Test No. 613; No. 4.—The fire was heavier at the close of the test than at the start. The coal burned with a medium length flame and caked. The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter.

Test No. 614; No. 4.—The coal burned with a medium length flame, and caked. The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter.

Test No. 615; No. 4.—The coal burned with a medium length flame, and caked. The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter.

Test No. 616; No. 4.—A hard, loose, brittle clinker formed on the dead plate.

Test No. 617; No. 4.—The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter. The loss up the stack was determined by using the analysis of gas from the combustion chamber.

Test No. 618; No. 4.—The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter.

Test No. 619; No. 4.—The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter.

Test No. 627; No. 6.—The ash and clinker were light in weight and brittle. The weight of the ash and refuse was determined from chemical analysis of the coal and the ash. The negative heat balance was due to unaccountable error.

Test No. 630; No. 6.—The load carried during the last hour was heavier than that carried during the rest of the test, but the feed of coal was not changed, so that the fire at the end of the test was really lighter. The weight of ash and refuse was determined from chemical analysis of the coal and the ash.

Test No. 631; No. 7.—The coal burned freely with a medium length flame. The weight of the ash and refuse was calculated from the chemical analysis of the coal and the ash.

Test No. 620; No. 7.—The coal was clean and bright and contained only a small amount of slate. The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter. The weight of the ash and refuse was determined by the chemical analysis of the coal and the ash.

Test No. 621; No. 7.—The coal caked badly in the fire. The moisture in the steam was determined by averaging the readings of the throttling and the separating calorimeter. The weight of the ash and refuse was calculated from the chemical analysis of the coal and the ash.

Test No. 623; No. 7.—The weight of the ash and refuse was determined from the chemical analysis of the coal and the ash.

Test No. 624; No. 7.—The fire at the close of the test was estimated to be between 200 and 250 pounds heavier than at the start. No ash was removed in this test. The weight of the ash and refuse was calculated from the chemical analysis of the coal and the ash. The test was too short for reliable results. The furnace doors were cracked continuously.

Test No. 625; No. 7.—The test was run to obtain good economy. The weight of the ash and refuse was determined from chemical analysis of the coal and the ash.

Test No. 626; No. 7.—The weight of the ash and refuse was determined from the chemical analysis of the coal and the ash. Flue-gas analysis is in error owing to a leak in the sampling pipe.

Test No. 639; No. 11.—The coal burned with a short, white flame, and caked. The fuel bed required considerable attention. A dark, heavy clinker formed on the grate; it was easily removed. Automatic air admission was not operated.

KANSAS.

Test No. 487; No. 2B (briquets).—Automatic air admission was not operated. The clinker was easily removed from the furnace.

Test No. 488; No. 2B (briquets).—The briquets burned freely, with a medium length flame. Automatic air admission was not operated. Steam was used in the ash pit for half of the test. A thick, nonporous clinker formed on the grate; it was broken up with difficulty.

Test No. 495; No. 2B (washed briquets).—The briquets burned freely with a short flame. Steam was used in the ash pit. Automatic air admission was not operated. In the first cleaning a light and thin clinker adhered somewhat to the grate. In the second cleaning the clinker was easily removed.

Test No. 311; No. 6.—Considerable free slate was present in the coal, also a large quantity of slate, iron, and sulphur combined. A considerable amount of gypsum was visible. The coal burned with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A dark brown, solid clinker formed on the grate and was easily removed.

Test No. 323; No. 6 (washed).—The coal burned freely and quickly, with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A layer of plastic clinker and free ash was formed on the grate; it was easily removed.

KENTUCKY.

Test No. 255; No. 1C.—The coal contained large quantities of bone coal and slate. The coal burned with a long, yellow flame, and caked, requiring frequent raking. A heavy clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 263; No. 1C.—The coal caked in the fire. A layer of dark, heavy, and solid clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 265; No. 1C.—The coal burned with a long flame. The volatile matter was distilled slowly. A heavy, red clinker formed over the grate; it was easily removed, owing to the presence of slate. Automatic air admission was operated.

Test No. 276; No. 5.—The coal burned freely; small pieces cracked off as soon as the coal was fired. A thin, solid, and very brittle clinker formed on the grate; it was easily broken and removed. Automatic air admission was operated.

Test No. 277; No. 5.—Small pieces of coal cracked off as soon as the coal was fired. The fire was easily handled. Automatic air admission was operated.

Test No. 270; No. 6.—Bone coal and slate occurred in the coal in large quantities. The coal burned with a long flame. A light, porous, whitish clinker formed on the grate; it was easily removed. The test was begun with exceptionally good furnace conditions. Automatic air admission was operated. Steam was used in the ash pit.

Test No. 271; No. 6.—The coal burned with a long flame. A light, porous clinker formed on the grate; it was easily broken and removed. Automatic air admission was operated. Steam was used in the ash pit. (Night test.)

Test No. 278; No. 7.—Gypsum, calcite, and slate were present in the coal. Sulphur occurred in both flakes and balls. The coal burned freely when there was sufficient air supply. The fuel bed required frequent raking. A solid layer of clinker formed over the grate after about two and one-half hours' run; it was easily removed. Automatic air admission was operated. No flue gas analyses were made on this test, as the Orsat apparatus was out of order.

Test 279; No. 7.—The coal burned freely, and the fuel bed required considerable attention. Automatic air admission was not operated. The clinker was easily removed from the grate. The furnace doors were cracked for a short interval after each firing.

Test No. 434; No. 8.—Gypsum was visible in the coal. Small quantities of slate and iron pyrites were present. The coal was very hard and contained a large amount of substance that resembled charcoal. It burned quickly, with a long, yellow flame, and caked. Automatic air admission was operated. A thin layer of very porous clinker formed on the grate; it was easily removed from the grate, but fused on the side walls.

Test No. 443; No. 8.—The coal burned with a long flame and caked, and the fuel bed required considerable attention. Automatic air admission was operated. A small amount of porous clinker of reddish-gray color formed on the grate; it was easily removed.

Test No. 462; No. 9B.—The coal burned rapidly and freely with a long flame. Automatic air admission was operated. Steam was used in the ash pit for one and one-half hours. A thick porous clinker of grayish color formed on the grate; it was easily removed.

MARYLAND.

Test No. 222; No. 1.—The coal was of crystalline structure and contained a small quantity of sulphur in thick layers. It was reduced to slack by shipping. It burned slowly with a short white flame, and caked. Clinker and free ash formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 231; No. 1 (washed).—The coal burned slowly and caked. The volatile matter was distilled off quickly. The clinker was easily removed. Automatic air admission was operated.

Test No. 232; No. 1 (washed).—A porous clinker formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 490; No. 2.—Automatic air admission was not operated. A small amount of clinker formed on the grate; it was easily removed.

Test No. 493; No. 2 (briquets).—Automatic air admission was not operated. The fire was easily handled.

Test No. 518; No. 2 (briquets).—The briquets were burned with a short flame. Automatic air admission was not operated. The fire was easily handled.

MISSOURI.

Test No. 319; No. 5.—The coal burned slowly with a medium length flame, and caked. Automatic air admission was operated. A thick layer of dark-brown clinker formed on the grate; it was easily removed.

Test No. 320; No. 5.—Sulphur occurred in the coal in thick layers in small quantity. Slate occurred in thick and in thin layers. A small quantity of clay was present. The coal burned quickly, and caked on account of the large amount of slack; it cracked in the fire. Automatic air admission was operated. A thick layer of heavy and solid clinker formed on the grate; at the first cleaning it was easily removed; at the second cleaning it was removed with difficulty. The fuel bed required considerable attention. The figures for moisture in steam were assumed.

Test No. 326; No. 6.—Sulphur occurred in the coal both as sulphur balls and in thick layers. Gypsum and calcite were quite prevalent in flakes. The coal burned freely, with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A heavy clinker of dark-red color formed on the grate; it was easily removed.

Test No. 327; No. 6.—The coal consisted of thin layers of black shiny coal alternated with a dull gray substance. It fractured in planes parallel and at right angles to the layers; it was broken with difficulty. Sulphur occurred in small quantity in thin layers and veins. Slate was present in small quantity in thin layers adhering to the coal. Gypsum and calcite occurred in large quantities in white opaque flakes in planes at right angles to the bedding planes. The coal burned freely, with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A heavy, compact clinker of dark-red color formed on the grate; it was easily removed.

Test No. 329; No. 7A (washed).—The coal burned freely and quickly with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A thin layer of solid and brittle clinker was formed on the grate; it was easily removed. The fire was easily handled.

Test No. 330; No. 7A (washed).—The coal burned freely and quickly with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A thin layer of solid, heavy clinker of dark-brown color formed on the grate; it was easily removed.

Test No. 332; No. 7B (washed).—The coal burned quickly with a long flame. Automatic air admission was not operated. A thick layer of solid, heavy clinker of dark-brown color formed on the grate; it was easily removed. The test was run to obtain high capacity, and forced draft was used.

Test No. 486; No. 10 (briquets).—The briquets burned freely with a long flame. Automatic air admission was not operated. Ash formed on the exterior of the briquets, reducing the rate of combustion. A large amount of dark-brown porous ash formed on the grate; it was easily removed. The fuel bed required considerable attention.

MONTANA.

Test No. 470; No. 2.—The coal burned freely and quickly. Automatic air admission was not operated. The fire was easily handled. Difficulty was experienced in separating the ash from the live fuel in cleaning fires.

Test No. 477; No. 3.—The coal burned freely. Automatic air admission was not operated. The fire was easily handled. Very porous clinker formed on the grate; it was easily removed.

NEW MEXICO.

Test No. 396; No. 3A.—The coal was rather soft. In structure it consisted of layers of bright black coal alternating with a dull gray substance. The fracture was irregular, forming rough surfaces. Slate occurred in large quantity in thick layers adhering to the coal. A large quantity of clay was present. The coal burned freely and quickly, with a long yellow flame. Automatic air admission was not operated. The fire was easily handled. Free ash, light in weight, formed on the grate.

Test No. 389; No. 3B.—The coal was soft and brittle; it crumbled when handled. Its structure was partly crystals and partly layers. The fracture was irregular, forming rough edges. Slate occurred in large quantity in thin and thick layers well distributed. Sulphur occurred in small quantity in thin layers. The coal burned freely

and quickly with a long, yellow flame, and cracked in the fire. The fire doors were partly open for one and one-half minutes after each firing. Free ash formed on the grate. Flue-gas analysis is questionable. Automatic air admission was not operated. The fire was easily handled.

Test No. 391; No. 3B.—The coal burned freely and quickly, with a long yellow flame, and cracked in the fire. Automatic air admission was not operated. The furnace doors were partly open after each firing for a short interval. The fire was easily handled. A thick layer of free ash formed on the grate. The flue-gas samples were questionable.

Test No. 392; No. 3B (washed).—The coal burned quickly, with a long yellow flame, and caked. Automatic air admission was not operated. The fire doors were partly open for a short interval after each firing. The fire was easily handled. Free ash formed on the grate.

Test No. 397; No. 4A.—The coal contained a large quantity of dirt, slate, clay, and stone. It burned freely. Automatic air admission was not operated. Free ash, light in color, formed on the grate.

Test No. 398; No. 4A (washed).—The coal contained a large quantity of dirt, slate, clay, and stone. It burned freely. Automatic air admission was not operated. Free ash, light in color, formed on the grate.

Test No. 395; No. 4B.—The coal was rather soft. Its structure was mostly layers of bright black coal alternating with layers of dull gray substance. The fracture was irregular, forming rough surfaces. Free slate occurred in small quantity. The coal burned quickly, with a long yellow flame, and caked. The fire was easily handled. Free ash formed on the grate and was easily removed.

Test No. 387; No. 5.—The structure of the coal was crystalline. The fracture was irregular, making rough surfaces. The coal was soft and crumbled in handling. It burned freely and quickly with a medium length flame. Automatic air admission was not operated. Fire doors were left open for one and one-half minutes after each firing. Large pieces of free ash formed on the grate. The fire was easily handled. Flue-gas samples were questionable.

NORTH DAKOTA.

Test No. 206; No. 3.—The coal burned with a short white flame and crumbled in the fire. A thin layer of very heavy clinker formed on the grate; it was easily removed. Free ash was white in color. Automatic air admission was not operated.

OHIO.

Test No. 191; No. 1.—Sulphur occurred in the coal in large balls and thick layers. A large quantity of free slate was visible. The coal burned slowly and caked. Heavy clinker of dark-gray color formed

on the grate; it was easily removed. Automatic air admission was operated.

Test No. 192; No. 1 (washed).—Heavy clinker of dark-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 193; No. 2.—Sulphur occurred in the coal in thin layers. The coal burned with a long flame. A reddish-brown clinker adhered to the grate; it was removed with difficulty. Automatic air admission was operated.

Test No. 197; No. 2 (washed).—The coal burned freely. A thin layer of dark heavy clinker fused to the grate; it was removed with difficulty. Automatic air admission was operated.

Test No. 203; No. 3 (washed).—The coal burned very freely, with a long flame. Light porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 188; No. 4.—The coal contained a large quantity of free slate. Thin layers of bright tarry coal alternated with a dull-gray, charcoal-like substance. The coal burned rapidly, with a long white flame, and caked. The clinker was heavy and of a dark-gray color; it was easily removed from the grate. Automatic air admission was operated.

Test No. 201; No. 4.—The coal burned freely. A dark-gray, heavy clinker adhered to the grate. Automatic air admission was operated.

Test No. 202; No. 4.—The coal burned freely, with a long yellow flame. A heavy dark-gray clinker adhered to the grate. Automatic air admission was operated.

Test No. 219; No. 4 (washed).—The coal burned with a long yellow flame. A very heavy dark-gray clinker formed on the grate. During the first part of the test the clinker did not adhere to the grate, but during the latter part it fused into the grate, and was removed with difficulty. Automatic air admission was operated.

Test No. 220; No. 4 (washed).—Sulphur appeared in the coal in layers. Considerable free slate was present. The coal burned with a long yellow flame; the small-sized coal caked badly. The volatile matter began to distill quickly after the coal was fired. A thin, solid, heavy layer of clinker formed over the grate; it was easily removed. Steam was used in the ash pit. Automatic air admission was operated.

Test No. 221; No. 4 (washed).—The coal burned with a long yellow flame. The volatile matter began to distill quickly after the coal was fired. A heavy nonporous clinker of a dark-brown color formed on the grate; it was removed in large pieces without difficulty. Automatic air admission was operated. Steam was used in the ash pit. The coal and ash samples in this test were mixed, by mistake.

The chemical determinations used are from the analysis of the same coal in the preceding test.

Test No. 186; No. 5.—The coal contained a considerable quantity of free slate. It burned with a long white flame. A layer of clinker formed on the grate and was easily removed owing to the presence of slate. The clinker was of medium weight, very porous, and of a deep purple color. Automatic air admission was operated.

Test No. 187; No. 5.—The coal burned freely, with a long yellow flame. The clinker was deep purple in color, medium in weight, porous, and loosely formed; it was easily removed from the grate, owing to the presence of slate. The free ash was of a gray color. Automatic air admission was operated.

Test No. 189; No. 5.—The coal contained a large quantity of free slate. Thin layers of bright tarry coal alternated with a dull charcoal-like substance. The coal burned rapidly, with a long white flame, and caked. A little porous clinker of a dark-gray color and large pieces of free ash formed on the grate; they were easily removed. Automatic air admission was operated.

Test No. 190; No. 5.—The coal burned rapidly, with a long white flame, and caked. The fire was easily handled. Clinker was of a dark-gray color. Automatic air admission was operated.

Test No. 284; No. 6.—The coal contained considerable bone coal and slate. A small quantity of gypsum was present. The coal burned freely, with a long flame. A dark heavy clinker formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 253; No. 6 (washed.)—The coal burned with a long flame. A thin solid layer of heavy clinker formed on the grate; it was removed with difficulty. Automatic air admission was operated.

Test No. 268; No. 7.—Much sulphur, in large balls and thick layers, occurred in the coal. A small quantity of free slate was present. Thin layers of bright coal alternated with a dull black substance. The coal cracked in the fire. A thick layer of heavy clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 269; No. 7.—The coal cracked in the fire. A thick layer of solid, heavy clinker formed on the grate; it was easily removed during the first cleaning; later it adhered to the grate and was removed with difficulty. Automatic air admission was operated. Steam was used in the ash pit.

Test No. 287; No. 8.—Much sulphur in large balls and thick layers occurred in the coal. The coal burned freely and cracked in the fire. Automatic air admission was operated. A thick layer of loose, heavy clinker formed on the grate but was easily removed.

Test No. 246; No. 9A.—The coal contained much sulphur in large balls and thick layers. Small quantities of gypsum and calcite were

present in transparent layers. The coal burned freely, with a long, yellow flame. A thin layer of porous clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was operated. Steam was used in the ash pit.

Test No. 249; No. 9A.—Sulphur occurred in the coal in thin flakes. Considerable quantities of gypsum and calcite were present. A small quantity of slate was visible. The coal burned freely. Volatile matter distilled slowly when the coal was fired. A soft, light clinker of dark-brown color formed over the grate. Automatic air admission was operated.

Test No. 250; No. 9A.—The coal burned freely with a long flame. Volatile matter distilled slowly when the coal was fired. A light, tough, porous clinker formed over the grate. During the early part of the test no steam was used in the ash pit and the clinker stuck badly to the grate. The use of steam in the ash pit thereafter prevented further trouble with the clinker. Automatic air admission was operated. This test was started immediately after closing a 10-hour run, so as to determine the effect on efficiency of starting the test with a very hot setting. (Night test.)

Test No. 252; No. 9A.—The coal burned freely. A thick layer of porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 224; No. 9B.—The coal burned with a long, yellow flame, and caked. A thick, porous clinker of a dark-gray color formed on the grate; it was easily removed. Automatic air admission was operated. Furnace temperature readings were taken from a black body placed against the inside wall of the combustion chamber; the readings were too low.

Test No. 241; No. 9B (washed).—The coal burned freely and cracked when thrown on the fire. A light, porous clinker and free ash formed on the grate; they were easily removed. Automatic air admission was operated. Steam was used in the ash pit.

Test No. 243; No. 9B (washed and dried).—The coal burned freely, with a long yellow flame, and caked. A light, porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 244; No. 9B (washed and dried).—The coal burned freely, with a long yellow flame. Light, porous clinker formed on the grate; it was easily removed. Automatic air admission was operated. (Night test.)

Test No. 469; No. 10.—The coal contained some iron pyrites and gypsum. It burned freely, with a long flame. Steam was used in the ash pit two hours before cleaning the fire. Automatic air admission was not operated. The lower furnace doors were cracked after

each firing. A grayish, porous clinker formed on the grate; it was easily removed.

Test No. 474; No. 11.—The coal burned freely, with a long flame. A heavy, loose clinker formed on the grate; it was easily removed.

Test No. 475; No. 11.—The coal burned with a long flame. A heavy, loose clinker formed on the grate; it was easily removed.

Test No. 483; No. 12.—The coal burned freely, with a white, short flame. The doors were cracked after each firing. Automatic air admission was not operated. The fire was easily handled. A brittle clinker formed on the grate; it was easily removed.

PENNSYLVANIA.

Test No. 207; No. 4.—The coal contained considerable free slate. Some clay occurred in layers about one-fourth inch thick. The coal burned freely, with a long, yellow flame; the small coal caked in the fire. A very light clinker of whitish-gray color formed over the grate; it was easily removed, owing to the presence of clay and slate. Automatic air admission was operated.

Test No. 208, No. 4.—The coal burned with a long, yellow flame; the small coal caked badly. The fuel bed required much attention. A light, fragile, porous clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 209; No. 4.—The coal burned with a long yellow flame; the fine coal caked badly. The fuel bed required much attention. A light, fragile clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 286; No. 5.—The coal burned freely. Automatic air admission was not operated. The clinker was porous, and was easily removed from the grate.

Test No. 194; No. 5 (washed).—The coal burned freely, with a long, bright flame. A gray, porous clinker, light in weight, formed over the grate; it was easily removed. Automatic air admission was operated.

Test No. 195; No. 5 (washed).—The fire was easily handled.

Test No. 217; No. 6.—The coal burned rapidly, with a long, yellow flame, and caked. A layer of light, porous clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 218; No. 6.—Free slate occurred in large quantity in layers. A small quantity of clay was present. The coal burned with a long, yellow flame. A little light clinker of light-gray color, and some free ash formed on the grate; they were easily removed. Automatic air admission was operated.

Test No. 333; No. 6 (briquets).—The briquets burned freely and slowly, with a short, white flame; they did not crumble. Auto-

matic air admission was operated. A thick layer of porous and brittle clinker formed on the grate; it was easily removed. The test was too short for reliable results. The briquets were broken in halves before firing.

Test No. 198; No. 7.—The coal used on this test contained much slack; it burned slowly and caked in the fire. A light, porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 307; No. 7.—The coal burned with a short flame. Automatic air admission was operated. Large pieces of free white ash formed on the grate; they were easily removed. This coal was exposed to the weather four and one-half months before testing.

Test No. 199; No. 7 (washed).—Gypsum and calcite were visible only in the ash and refuse. The coal burned with a long, yellow flame, and caked considerably in the fire, probably owing to the presence of small coal. The fuel bed required much attention. Light porous clinker and free ash of a light-gray color formed on the grate; they were easily removed. Automatic air admission was operated.

Test No. 236; No. 8.—The coal burned with a short, white flame, and caked. A little light clinker of a light-gray color, and pieces of free ash formed on the grate; they were easily removed. Automatic air admission was not operated.

Test No. 237; No. 8.—The coal burned slowly, with a short, white flame, and caked. A light clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 238; No. 8.—The coal burned slowly, with a short, white flame, and caked. The clinker was easily removed from the grate. The fuel bed required considerable attention. Automatic air admission was not operated.

Test No. 239; No. 8.—The coal burned slowly, with a short, white flame, and caked. The clinker was easily removed. Automatic air admission was not operated.

Test No. 242; No. 8 (dried).—The coal burned slowly, with a short, white flame, and caked. A light porous clinker formed on the grate; it was easily removed. Automatic air admission was operated. The coal was fired shortly after leaving the dryer. The temperature of the coal when fired was 170° F.

Test No. 227; No. 10.—The coal burned freely, with a long, yellow flame, and cracked in the fire. A small amount of heavy clinker of light-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 228; No 10.—Thin layers of bright shiny coal alternated with a dull-brown substance. The coal was broken with difficulty.

It fractured irregularly; the broken pieces had sharp edges and points. It burned with a long, yellow flame and cracked in the fire. Heavy clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 229; No. 10.—The coal burned freely, with a long, yellow flame, and cracked in the fire. A heavy clinker of light color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 472; No. 15.—The coal caked in the fire. Steam was used in the ash pit. Automatic air admission was not operated. The clinker adhered to the grate and was removed with difficulty.

Test No. 473; No. 15.—The coal burned with a short flame, and caked; it cracked in the fire. Steam was used in the ash pit. Automatic air admission was not operated. The fuel bed required considerable attention.

Test No. 467; No. 15 (briquets).—The briquets burned with a short flame. Steam was used in the ash pit. Automatic air admission was not operated. A thin clinker of red and black color formed on the grate, and was removed with difficulty on account of the bad condition of the grate bars. The clinker impeded the air supply.

Test No. 468; No. 16 (briquets).—The briquets burned slowly, with a medium length flame. Automatic air admission was not operated. A heavy, brittle clinker of grayish color formed on the grate; it was easily removed.

Test No. 471; No. 16.—The coal caked in the fire. The fuel bed required considerable attention. Steam was used in the ash pit five hours before cleaning. Automatic air admission was not operated. A grayish, porous clinker formed on the grate; it was easily removed.

Test No. 496; No. 17.—The coal burned with a short flame, and caked. The fuel bed required frequent attention. Automatic air admission was not operated. A light, porous clinker of a very dark color formed on the grate, but was easily broken up and removed.

Test No. 506; No. 17.—The coal caked in the fire. The fuel bed required much attention. Automatic air admission was not operated. The clinker was easily removed.

Test No. 499; No. 18 (briquets).—The briquets burned freely and did not crumble in the fire. The furnace was very hot. Automatic air admission was not operated. The fire was easily handled.

Test No. 515; No. 18 (briquets).—The coal burned with a short flame. Automatic air admission was not operated. The fire was easily handled.

Test No. 498; No. 19.—The coal burned with a short flame. Automatic air admission was not operated. A porous clinker formed on the grate; it was easily removed. The fire was easily handled.

Test No. 508; No. 19 (briquets).—Automatic air admissoin was not operated. The fire was raked frequently to break up the briquets. The clinker was easily removed.

Test No. 512; No. 20 (washed briquets).—Automatic air admission was not operated. The briquets held together well in the fire. The fire was easily handled.

Test No. 514; No. 20 (briquets).—Automatic air admission was not operated. The furnace was very hot. The fire was easily handled.

Test No. 510; No. 22 (briquets).—Automatic air admission was not operated. The fire was easily handled.

RHODE ISLAND.

Test No. 401; No. 1.—The coal burned slowly, with a short, bluish flame. It became hot and fused together, cutting off the air supply through the grate. Hooking the fire helped slightly. Small pieces of coal burned more completely than large ones. About $\frac{3}{4}$-inch coal would be the best size for steaming purposes. Large pieces burn only on the surface, because the ash fuses and adheres to the coal, thus insulating the inner portion. Low capacity was developed, owing to the fact that high enough draft could not be obtained with the fan blower. In order to develop the rated capacity, a draft of 3 to 4 inches of water would be necessary. A rocking grate would be preferable to a flat grate. Pressure was used in the ash pit. Automatic air admission was not operated. The furnace temperature was too low to be read by the Wanner optical pyrometer.

TENNESSEE.

Test No. 344; No. 1.—Sulphur balls occurred in the coal in small quantity. Thin layers of slate were present. The coal burned freely. Automatic air admission was operated. A fragile, porous clinker light in weight and of a dark grayish-red color formed over the grate; it was easily removed.

Test No. 345; No. 1.—The coal burned freely, with a long flame. Automatic air admission was operated. A light, porous clinker formed on the grate; it was easily removed.

Test No. 346; No. 1.—Lumps of slate were present in the coal. The coal burned freely, with a long flame. The fire was easily handled. Automatic air admission was operated. The clinker was easily removed.

Test No. 411; No. 1 (washed briquets).—The briquets held together well in the fire and burned with a long flame. Automatic air admission was not operated. The fire was easily handled. The test was too short for reliable results.

Test No. 409; No. 1 (washed briquets).—The briquets held together well in the fire and burned with a long flame; they were broken in

halves before firing. Automatic air admission was not operated. A small amount of brown clinker formed on the grate; it was easily removed. The flue-gas temperature was questionable.

Test No. 367; No. 2.—The coal contained some lumps of heavy, reddish substance, probably iron oxide. It burned very freely, with a long flame, and cracked in the fire. Steam was used in the ash pit. Automatic air admission was not operated. The furnace doors were cracked after each firing. A loose, light clinker of reddish-brown color formed on the grate; it was easily removed. The combustion wall fell during the test. The test was run to obtain high capacity.

Test No. 368; No. 2.—The coal burned freely, with a long flame, and cracked in the fire. Automatic air admission was not operated. Steam was used in the ash pit two hours before cleaning the fire. The furnace doors were cracked two minutes after each firing. A loose, porous clinker of reddish-brown color formed on the grate; it was easily removed. The combustion wall was down during the entire test.

Test No. 369; No. 2.—The coal burned freely. Automatic air admission was not operated. A light, brittle, porous clinker of reddish-brown color formed on the grate; it was easily removed.

Test No. 349; No. 3.—The coal burned freely, with a long flame. Steam was used in the ash pit after 11 a. m. Automatic air admission was operated. A solid clinker formed over the grate; it was easily broken up and removed. Flaming in the hood was noticed at firing intervals for about one hour.

Test No. 350; No. 3.—The coal contained considerable quantities of slate and bone coal. It burned freely, with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A thin layer of solid and fragile clinker formed on the grate; it was easily removed, owing to the presence of a large amount of slate. The test was run to obtain high capacity.

Test No. 355; No. 4.—The coal burned freely, with a long flame. One vane of the automatic air admission was left open continuously. A very light and porous clinker formed on the grate; it was easily removed. The combustion wall was partly down during the test.

Test No. 356; No. 4.—Small quantities of slate and flake sulphur were distributed through the coal. The coal burned freely, with a long flame. Automatic air admission was operated. A loose clinker formed on the grate; it was easily removed. The test was run to obtain high capacity.

Test No. 405; No. 4 (briquets).—The briquets did not crumble in the fire and burned with a long flame; they were broken in halves before firing. Automatic air admission was not operated. The fire was easily handled.

Test No. 352; No. 5.—Sulphur was present in the coal in considerable quantity. Some slate was visible. The coal was small and very wet. It burned rapidly, with a long flame. The clinker was very brittle and porous and was easily removed from the grate. Automatic air admission was operated.

Test No. 357; No. 5.—The coal contained small quantities of slate and fire clay, also a few pieces of pyrites. It burned freely, with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A layer of reddish-brown, solid, heavy clinker formed on the grate; it was easily broken up and removed.

Test No. 358; No. 5.—The coal burned freely, with a long flame. Steam was used in the ash pit. Automatic air admission was operated. A layer of clinker formed over the grate; it was easily broken up and removed. The test was run to obtain high capacity.

Test No. 379; No. 6.—The coal contained a considerable quantity of lump slate; it burned with a short flame, and caked. One-quarter of the observations of furnace temperature were too low to be read by the Wanner optical pyrometer; the average of the furnace temperature was not representative of the test. Steam was used in the ash pit for one hour before cleaning. Automatic air admission was operated. A dark, porous clinker formed on the grate; at the first cleaning it was removed with difficulty; at the second cleaning it was easily removed. A new mixing wall was in the combustion chamber.

Test No. 381; No. 6.—Seventeen out of twenty-seven observations of furnace temperature were too low to be read by the Wanner optical pyrometer; the average is not representative of the test. The coal burned with a medium length flame. The fuel bed required considerable attention. Automatic air admission was operated. A light, porous clinker of brown color adhered slightly to the grate.

Test No. 372; No. 7A.—A considerable quantity of slate and iron pyrites in lumps was present in the coal. The coal was of medium hardness and contained some bone coal. It burned rapidly, with a long flame, and caked. The furnace doors were cracked for a short interval after each firing. Automatic air admission was not operated. The clinker was easily broken up and removed.

Test No. 373; No. 7A.—The coal burned very rapidly, with a long flame, and cracked in the fire. Automatic air admission was not operated. The furnace doors were cracked after each firing. The fire was easily handled. The test was run to obtain high capacity.

Test No. 374; No. 7A.—The coal burned rapidly, with a long flame, and caked. Automatic air admission was not operated. A dark, porous clinker formed on the grate; it was easily removed.

Test No. 406; No. 7B (washed briquets).—The briquets held together well in the fire and burned with a long flame. They were broken in halves before firing. Automatic air admission was not operated. A

small amount of reddish-brown clinker formed on the grate; it was easily removed. Very little smoke was made.

Test No. 384; Nos. 8A and 8B.—The coal contained slate, sulphur, and gypsum in large quantities. It caked, probably due to the presence of small coal. Automatic air admission was operated. A black, thin, and nonporous clinker adhered somewhat to the grate.

Test No. 385; Nos. 8A and 8B.—The coal caked in the fire. Most of the combustion took place before the gases left the mixing walls. Automatic air admission was not operated. A black, thin, and nonporous clinker adhered somewhat to the grate. Pressure was used in the ash pit. The moisture in the steam was estimated.

Test No. 388; Nos. 8A and 8B (washed).—The coal burned quickly, with a long yellow flame, and caked. Automatic air admission was not operated. The fire doors were cracked one and one-half minutes after each firing. A thin layer of solid, heavy, plastic clinker formed on the grate; it was easily removed. Flue-gas analysis was questionable.

Test No. 363; No. 9A.—The coal did not appear to have been formed in layers; it crumbled easily without showing any planes of cleavage. Sulphur occurred in small quantity and in thin layers attached to the coal. Some slate was present. The coal burned with a long flame, and caked. Automatic air admission was not operated. A loose clinker formed on the grate; it was easily removed. Furnace doors were cracked continuously.

Test No. 364; No. 9A.—The coal burned with a long flame, and caked. Automatic air admission was not operated. A slightly plastic clinker, light in color, formed on the grate; it was easily removed. The furnace doors were cracked for one minute after each firing.

Test No. 365; No. 9A.—The coal burned with a long flame, and caked. Automatic air admission was not operated. The clinker was brittle and slightly porous and was easily removed from the grate.

Test No. 393; No. 9B (washed briquets).—The briquets were hard and did not break when dropped from a height of 15 feet on the brick pavement. All briquets were fired whole except the first two carloads, which were broken in halves; they swelled up in the fire and gradually cracked into small pieces, burning freely and quickly with a long white flame. The fire was easily handled. Automatic air admission was not operated. A thin layer of solid and heavy clinker, of a light-brown color, formed on the grate; it was removed without much difficulty.

Test No. 407; No. 10 (washed briquets).—One-third of the observations of furnace temperature were too low to be read by the Wanner optical pyrometer; the average is not representative of the test. The briquets were broken in halves before firing; they did not crum-

ble in the fire and burned with a long flame. The test was too short for reliable results. Automatic air admission was not operated.

Test No. 408; No. 10 (washed briquets).—The briquets did not crumble in the fire and burned with a long flame. Automatic air admission was not operated. The flue-gas temperature is questionable. The test was too short for reliable results.

TEXAS.

Test No. 291; No. 4.—The coal burned freely, with a short flame. Automatic air admission was not operated. A light, white, free ash formed on the grate; it was easily removed. Forced draft was used.

Test No. 298; No. 4.—The coal burned with a long flame; the clinker was very porous. Automatic air admission was not operated.

Test No. 303; No. 4.—The coal burned freely, with a long flame; it crumbled into dust in the fire. Automatic air admission was not operated. Large pieces of heavy clinker formed on the grate; they were easily removed. The test was too short for reliable results.

UTAH.

Test No. 402; No. 2 (briquets).—The briquets held together well in the fire; they were broken in halves before firing. Automatic air admission was not operated. The fire was easily handled.

Test No. 403; No. 2 (briquets).—The briquets held together well in the fire. Automatic air admission was not operated. The fire was easily handled. The test was too short for reliable results.

Test No. 404; No. 2 (briquets).—The briquets burned freely, with a medium length flame, and crumbled badly in the fire. Automatic air admission was not operated. The fire was easily handled. Nearly one-half of the furnace temperature readings were too low to be recorded by the Wanner optical pyrometer.

VIRGINIA.

Test No. 281; No. 1.—The coal burned with a long flame. The clinker was porous. Automatic air admission was operated.

Test No. 282; No. 1.—The coal burned rapidly, with a long flame; the fine coal caked. The clinker was porous and easily removed; it contained much burned slate. Automatic air admission was not operated.

Test No. 247; No. 2.—The coal contained a small quantity of slate. Thin layers of shiny black coal alternated with a dull black substance. The coal fractured giving irregular sharp edges; it burned freely with a long flame, and cracked in the fire. Free ash and a very little clinker formed on the grate; it was easily removed. Automatic air admission was operated. Steam was used in the ash pit.

Test No. 251; No. 2.—The coal burned freely, with a long flame, and cracked in the fire. Free ash and a very little porous clinker formed on the grate; they were easily removed. Automatic air admission was operated.

Test No. 256; No. 2.—Sulphur occurred in the coal in thin layers. The coal burned with a long flame, and caked. A light porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 260; No. 2 (washed).—The coal burned freely, with a long flame. A dark, porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 280; No. 3.—Automatic air admission was not operated. The clinker and refuse were easily removed from the furnace.

Test No. 283; No. 3.—A thin solid clinker adhered to the grate. Automatic air admission was operated.

Test No. 240; No. 4.—The coal contained a small quantity of slate in thin layers adhering to the coal. A large quantity of bone coal was present. Thin layers of bright coal, with metallic luster, alternated with a dull black substance. The coal fractured irregularly, forming sharp edges. It burned freely. A thin layer of heavy clinker fused into the grate and was difficult to remove. Steam was used in the ash pit. Automatic air admission was operated.

Test No. 248; No. 4.—The coal contained a small quantity of slate. It burned freely, with a long flame, and cracked in the fire. Automatic air admission was operated. Steam was used in the ash pit. A thin layer of very heavy clinker formed on the grate; it was easily removed. One hundred and seventy-five pounds of limestone was spread over the grate immediately after starting the test, to prevent clinker from fusing into the grate as it did in test No. 240. The per cent of clinker in the refuse was not determinable.

Test No. 254; No. 4.—The coal contained small quantities of slate, gypsum, and calcite. It burned with a long, yellow flame. Automatic air admission was operated. A heavy, red clinker formed on the grate; it was easily removed. Two hundred and eleven pounds of limestone were spread on the grate at the start of the test, to prevent clinker from fusing into the grate as it did in test No. 240.

Test No. 476; No. 5A.—The coal burned better with a high draft. The fuel bed required considerable attention. Considerable porous ash formed on the grate. Automatic air admission was not operated. Forced draft was used for about two hours.

Test No. 482; No. 5A.—The coal burned rapidly and freely. The fire was easily handled. Automatic air admission was not operated. A large amount of loose clinker formed on the grate; it was easily removed. Forced draft was used.

Test No. 494; No. 5B (briquets).—Automatic air admission was not operated. The clinker was easily removed from the furnace.

Test No. 507; No. 6.—The coal caked in the fire. The fuel bed required much attention. Steam was used in the ash pit. Automatic air admission was not operated. The clinker was easily removed. Forced draft was used.

WASHINGTON.

Test No. 290; No. 1B.—The coal burned freely, with a short flame. Automatic air admission was operated. A light, white free ash formed on the grate; it was easily removed.

Test No. 359; No. 2.—The coal was rather hard; thin layers of bright black coal alternated with layers of a dull black substance. The fuel fractured most easily in planes at right angles to the layers of structure. Other fractures were rough and irregular. Sulphur occurred as iron pyrites in small quantities in thin layers well distributed. Slate was present in large quantities in thick layers adhering to the coal. Gypsum and calcite occurred in small quantity in thin, somewhat transparent flakes. Bituminous shale was visible in large quantity in thick layers (¼ to 1 inch) adhering to the coal; the shale had the appearance of gray sandstone. The coal contained an occasional lignitic layer. It burned freely, with a long flame, and cracked in the fire. The gas analysis was taken on one-half of the test only, and was assumed to represent the whole test. Automatic air admission was not operated. A thick layer of light, porous clinker of light-gray color formed on the grate; it was easily removed. The furnace doors were cracked for a short interval after each firing.

Test No. 360; No. 2.—The coal burned freely and cracked in the fire. Steam was used in the ash pit. Automatic air admission was not operated. A thick layer of clinker, brown in color, formed on the grate; it was easily broken up and removed. The flue-gas temperature was estimated for the heat balance.

Test No. 361; No. 2.—The coal burned with a medium-length flame and caked. A brittle clinker of brown color formed on the grate; it was easily removed.

Test No. 412; No. 2 (briquets).—The briquets held together well in the fire and burned rapidly. The small briquets burned better and with a hotter fire than the large ones. Automatic air admission was not operated. A small amount of heavy, brittle, slightly porous clinker of reddish-brown color formed on the grate. The moisture in the steam was estimated.

WEST VIRGINIA.

Test No. 179; No. 13.—The coal contained a small quantity of free slate; it was granular in structure with occasional layers. It burned rapidly and caked. A thin layer of loose clinker, dark in color, formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 180; No. 13.—The coal caked in the fire. Very little clinker was formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 178; No. 14.—The coal burned rapidly and caked in the fire. Steam was used in the ash pit during the afternoon. The clinker was easily removed during the first cleaning; in the second cleaning it adhered to the grate and was difficult to remove. Automatic air admission was operated.

Test No. 181; No. 14.—The coal burned rapidly and caked. When the test was started 290 pounds of crushed limestone was spread over the grate to prevent the clinker from melting into it as it did on test 178. Free ash formed on the grate; it was easily removed. The percentage of clinker in the refuse was not determinable. Automatic air admission was operated.

Test No. 214; No. 15.—The coal burned slowly. A thick layer of heavy, dark-gray clinker fused to the grate; it was removed with difficulty. Automatic air admission was operated.

Test No. 215; No. 15.—Sulphur occurred in the coal in thin layers, well distributed. A small quantity of slate was present. The coal caked in the fire. A thick layer of heavy, dark-gray clinker formed on the grate; it was easily removed. Steam was used in the ash pit. Automatic air admission was operated.

Test No. 216; No. 15.—The coal burned rapidly and caked. A thick layer of heavy, dark-gray clinker formed on the grate; it was easily removed. Automatic air admission was operated. Forced draft was used.

Test No. 304; No. 16A.—The coal burned freely, with a long, yellow flame. Automatic air admission was not operated. The fire doors were cracked after each firing. A thin layer of black, heavy clinker formed on the grate.

Test No. 305; No. 16A.—The coal burned freely, with a long flame. Automatic air admission was operated. A thin layer of solid, dark, heavy clinker formed on the grate; it was easily removed.

Test No. 225; No. 17.—The coal burned rather slowly, with a short, white flame, and caked. The fuel bed required much attention. A thick layer of heavy clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 226; No. 17.—The coal was easily broken; when fractured it showed small irregular crystalline grains. It burned with a short, white flame and caked. The fuel bed required much attention. A heavy clinker of a light-gray color formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 230; No. 17 (washed).—The coal burned slowly. A thin layer of solid, heavy clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 261; No. 18.—The coal burned freely, and cracked in the fire. Clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 262; No. 18.—The fire was easily handled. Automatic air admission was operated.

Test No. 285; No. 19.—The coal caked in the fire. Automatic air admission was not operated. A thin layer of solid, heavy plastic clinker formed on the grate; it was easily removed.

Test No. 289; No. 19.—The coal burned slowly and caked. Steam was used in the ash pit. Automatic air admission was not operated. A thin layer of dark, heavy, solid clinker formed on the grate; it was easily removed.

Test No. 331; No. 19 (briquets).—The briquets burned freely and quickly, with a short flame, and did not crumble in the fire; they were broken in halves before firing. Automatic air admission was not operated. A thin layer of solid, heavy clinker, of dark-brown color, formed on the grate; it was easily removed. The test was too short for reliable results.

Test No. 272; No. 20.—Slate and bone coal were somewhat prevalent in the coal; some clay was visible. The coal burned freely, with a long, yellow flame. A light, porous clinker formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 273; No. 20.—The coal burned freely, with a long, yellow flame. A light, porous clinker, white in color, formed on the grate; it was easily removed, owing to the presence of slate. Automatic air admission was operated.

Test No. 264; No. 20 (washed).—The fire was easily handled. Automatic air admission was operated.

Test No. 266; No. 20 (washed).—The fire was easily handled. Automatic air admission was operated.

Test No. 274; No. 21.—The coal burned very freely. The fire was easily handled. Automatic air admission was operated.

Test No. 275; No. 21.—The fire was easily handled.

Test No. 296; No. 21.—The coal burned freely and cracked in the fire. The fire was easily handled. Automatic air admission was operated.

Test No. 267; No. 21 (washed).—The coal burned freely. The fire was easily handled. Automatic air admission was operated.

Test No. 446; No. 22A.—The coal burned rapidly with a short flame. The fuel bed required considerable attention. Automatic air admission was operated. The test was run to obtain high capacity. Clinker formed on the grate in lumps; it was easily removed.

Test No. 447; No. 22A.—The coal burned with a short flame and caked. The fuel bed required considerable attention. Automatic

air admission was operated. The clinker was easily removed from the furnace.

Test No. 454; No. 22A (washed).—The coal caked in the fire. The fuel bed required considerable attention. Automatic air admission was operated. A small quantity of brittle, porous clinker formed on the grate; it was easily removed.

Test No. 438; No. 22B.—The coal burned with a bright flame. The fire was easily handled. Automatic air admission was operated.

Test No. 439; No. 23A.—The coal had a bright luster similar to anthracite. It contained a large amount of slate and a small quantity of iron pyrites. It burned rapidly with a medium flame and caked. The lower fire doors were cracked throughout the test. Automatic air admission was operated. A thin layer of solid clinker of medium weight formed over the grate and adhered to the side walls; it was removed with some difficulty.

Test No. 440; No. 23A.—The coal burned quickly with a medium-length flame and caked. Automatic air admission was operated. A solid clinker of grayish-brown color formed on the grate; it was broken up with difficulty, but was easily removed.

Test No. 444; No. 23B (washed).—The coal burned with a long flame and caked. The fuel bed required considerable attention. Automatic air admission was operated. A thin, tough, dark-brown, solid clinker, impeding the air supply, formed on the grate and was removed with difficulty.

Test No. 445; No. 23B (washed).—The coal burned quickly with a bright flame and caked. The fuel bed required considerable attention. Automatic air admission was operated. In the first cleaning a thick, brittle clinker formed on the grate; it was easily removed. In the second cleaning a thin layer of clinker of dark-brown color adhered to the grate; it was removed with difficulty.

WYOMING.

Test No. 196; No. 2B.—Slate appeared in large quantity, adhering to the coal. The coal burned with a short, white flame. Light, free ash, white in color, formed on the grate; it was easily removed. Automatic air admission was operated.

Test No. 210; No. 2B.—A large quantity of slate appeared in the coal in thin layers, adhering to the coal. The coal fractured irregularly; it burned quickly and caked in the fire. A light, white free ash formed on the grate. Automatic air admission was operated.

Test No. 213; No. 2B.—The fire was easily handled. Automatic air admission was not operated. A very light ash, of light color, formed on the grate. The test was run to obtain high capacity.

Test No. 211; No. 3.—A large quantity of sulphur occurred in thick layers, adhering to the coal. Much gypsum and calcite were

present in large transparent flakes. A large quantity of slate occurred in thin layers, alternating with layers of coal. Some clay was visible. The coal burned with a short, white flame and cracked in the fire. A heavy dark-gray clinker adhered slightly to the grate. Automatic air admission was operated. The test was made to obtain maximum efficiency.

Test No. 212; No. 3.—The coal burned with a short white flame. The clinker was heavy and of a dark-gray color. During the first part of the test loose clinker formed on the grate, and was easily removed; during the latter part of the test clinker adhered to the grate, and was hard to remove. Automatic air admission was not operated.

Test No. 223; No. 3 (washed).—The coal burned freely, with a short, white flame, and cracked in the fire. A thin layer of dark, heavy clinker formed on the grate; it was easily removed on first cleaning. On second cleaning it adhered somewhat to the grate. Automatic air admission was not operated. Steam was used in the ash pit. The combustion chamber temperature on this test was taken by placing a D-shaped body against the inside wall of the combustion chamber. The temperature readings were too low.

Test No. 399; No. 4.—The coal was not stratified and contained a little gypsum. It burned freely when the fire was thin. Automatic air admission was not operated. The fire was easily handled.

Test No. 400; No. 6.—The coal contained some gypsum and small amounts of dirt and slate. It crumbled badly. The fire was easily handled. Automatic air admission was not operated. A small quantity of porous clinker formed on the grate.

Test No. 419; No. 6 (briquets).—The briquets held together in the fire; they burned slowly with a short flame. The fire was easily handled. Automatic air admission was not operated. A 5-inch fire gave much better results than a 12-inch fire. The moisture in the steam was estimated.

ARGENTINA.

Test No. 451; No. 1.—The coal burned poorly. The fuel bed required frequent attention. Automatic air admission was not operated. The fire was cleaned by raking out lumps of clinker. Forced draft was used.

Test No. 458; No. 1 (washed).—One-quarter of the observations of furnace temperature were too low to be read by the Wanner optical pyrometer. The average is not representative of the test. The coal burned quickly. Automatic air admission was not operated. A thick, porous, and brittle clinker formed on the grate and fused with the coal; it was easily removed. Forced draft was used.

Test No. 485; No. 1 (washed briquets).—The briquets burned slowly and did not break down in the fire. Automatic air admission was not operated. The refuse and coal formed large lumps in the furnace that were broken up with difficulty. Forced draft was used. The test was too short for reliable results.

BRAZIL.

Test No. 172; No. 1.—A small quantity of sulphur in large balls and thick layers occurred in the coal. Gypsum and calcite were present in thin, opaque flakes. Much slate occurred in thick layers, adhering to the coal. The coal burned very freely, with a short, white flame, and crumbled in the fire. Light, white, free ash formed on the grate; it was easily removed. Automatic air admission was not operated.

Test No. 173; No. 1.—The coal burned freely with a short, white flame, and crumbled in the fire. Large pieces of light, white, free ash formed on the grate; they were easily removed. Automatic air admission was not operated. Forced draft was used.

MIXED COALS.

Test No. 348.—Small quantities of sulphur and slate were visible in the coal. The coal burned freely and slowly, with a long, yellow flame. Automatic air admission was operated. The clinker was solid, heavy, and plastic in the fire. In the first cleaning a thick layer of loose clinker formed on the grate; it was easily removed. In the second cleaning, plastic clinker fused over the grate and was removed with difficulty.

Test No. 347.—The coal burned freely, with a long flame, although the presence of snow retarded its quick ignition. Automatic air admission was operated. A fragile clinker, dark in color, formed over the grate; it was easily removed. The test was run to obtain high capacity.

Test No. 351.—The coal burned freely and slowly with a long flame. Automatic air admission was operated. A thick layer of loose, light, porous clinker formed on the gate; it was easily removed. The test was run to obtain high capacity.

Test No. 362.—One-third of the observations of furnace temperature were too low to be read by the Wanner optical pyrometer; the average is not representative of the test. The coal burned freely and slowly with a long flame. The furnace doors were cracked for two minutes after each firing. Automatic air admission was not operated. A thick layer of plastic and somewhat porous clinker formed on the grate; it was easily removed.

Test No. 366.—The coal burned so quickly that it was necessary to fire by the spreading method. Steam was used in the ash pit just before cleaning. Automatic air admission was not operated.

The furnace doors were cracked for one and one-half minutes after each firing. A heavy, plastic clinker formed on the grate; it was easily removed. The test was too short for reliable results.

Test No. 370.—The coal burned with a short flame and caked. Automatic air admission was not operated. A black, porous, plastic clinker formed on the grate; it was easily removed. The test was too short for reliable results.

Test No. 371.—The coal burned with a short flame and caked. Automatic air admission was not operated. A black, plastic clinker formed on the grate; it was easily removed. The furnace temperature was too low to be read by the Wanner optical pyrometer. The combustion chamber was a faint red at all times. The test was too short for reliable results.

PENNSYLVANIA AND VIRGINIA.

Test No. 245; one-third Pennsylvania No. 8 dried and two-thirds Virginia No. 4.—Gypsum, calcite, and bone coal occurred in the coal in small quantities. A little slate was present. The coal burned with a long, yellow flame and caked. A solid clinker formed over the grate; it was easily removed. Automatic air admission was operated. The boiler was fired only two hours before starting the test.

UTAH AND RHODE ISLAND.

Test No. 414 (briquets).—One-quarter of the observations of furnace temperature were too low to be read by the Wanner optical pyrometer; the average is not representative of the test. The briquets did not crumble in the fire and burned with a short flame. Automatic air admission was not operated. A heavy layer of plastic clinker formed on the grate; it was broken with some difficulty.

Test No. 415 (briquets).—The briquets did not crumble in the fire and burned with a short flame. Automatic air admission was not operated. A heavy layer of plastic clinker formed on the grate; it was broken with some difficulty. Forced draft was used.

Test No. 416 (briquets).—The briquets crumbled in the fire, did not cake, and burned with a long flame. Automatic air admission was not operated. A large amount of free ash formed on the grate; it was easily removed. Forced draft was used.

SPECIAL TESTS.

ILLINOIS.

Test No. 500 (Collinsville).—The coal burned with a long flame and caked. Automatic air admission was not operated. A solid, plastic clinker formed over the grate; it was removed with some difficulty.

The average thickness of the incandescent fuel bed was about 3 inches.

Test No. 501 (Collinsville).—The coal burned with a long flame. Automatic air admission was not operated. The average thickness of the incandescent fuel bed was about 3 inches. The fire was easily handled.

Test No. 502 (Collinsville).—Forced draft was necessary to keep the fire hot after clinker formed. Automatic air admission was not operated. The fire required frequent cleaning.

Test No. 503 (Collinsville).—The lower furnace doors were cracked continuously. Automatic air admission was not operated. The fire required frequent cleaning. The load was very uniform.

Test No. 504 (Collinsville).—The furnace doors were cracked continuously. Automatic air admission was not operated. The average thickness of the incandescent fuel bed was about 3 inches. The fire was easily handled.

Test No. 505 (Collinsville).—Automatic air admission was not operated. The furnace was very hot. The fire was easily handled. The average thickness of the incandescent fuel bed was about 3 inches. Forced draft was used.

Test No. 517 (Collinsville).—Automatic air admission was not operated. The fire required frequent cleaning.

WASHERY REFUSE.

Test No. 479.—Automatic air admission was not operated. A brittle clinker formed on the grate; it was easily removed. The fire was cleaned every hour. Forced draft was used.

MIXED COKE.

Test No. 519.—The average thickness of the incandescent fuel bed was 5 inches. Automatic air admission was not operated. The fire was easily handled. Forced draft was used.

PART II.

STUDY AND DISCUSSION OF STEAMING TESTS MADE AT THE FUEL-TESTING PLANT.

INTRODUCTION.

The steaming tests described in the first part of this bulletin comprise without doubt the largest number of boiler trials with complete series of observations ever made with one type of boiler under practically similar conditions. These features make the tests peculiarly fitted for analytical study and for comparison of results. Of course when any such comparisons are made, each test must be examined in detail as to the conditions under which it was conducted and the character of the coal. In determining what tests may be used in any comparison, a great deal depends on the basis on which the comparison is to be made.

The authors' familiarity with the details of the tests renders them particularly well fitted to make comparisons of the results of the tests and to draw deductions. Therefore they have made a study of the tests. In this study they have made numerous comparisons and arrived at some rational conclusions. Their methods of study and the conclusions which they draw are presented as a part of this bulletin, in the belief that they will prove of value to the practical steam engineer. The reader should keep constantly in mind that the conclusions are mostly drawn from the results of the tests that were made with a hand-fired furnace, and that they apply directly to similar hand-fired furnaces. When applied to other furnaces some modifications are necessary, although the fundamental principles underlying these deductions hold true for all furnaces.

PARTS OF A STEAM-GENERATING APPARATUS, THEIR FUNCTIONS AND EFFICIENCIES.

A steam-generating apparatus is a device in which the heat developed by the combustion of any fuel is utilized to evaporate water contained in a closed metallic vessel called the boiler. The effectiveness or the efficiency of the steam-generating apparatus is measured by the ratio of the heat that is absorbed in heating and evaporating the water to the total heating value of the fuel delivered to the apparatus. The heating value of the fuel is computed from a determination in a bomb calorimeter. The ratio of the heat ab-

sorbed by the boiler to the heat contained in the fuel delivered to the apparatus is called the over-all efficiency of the steam-generating apparatus, and is the item in which the user of the apparatus, or the man who pays the coal bill, is most interested. The student of steaming tests, however, is not satisfied with such general information, and if this over-all efficiency is low he analyzes the data and the results of the test and endeavors to ascertain which part of the apparatus is to be blamed for poor economic results. He therefore separates the apparatus into its component parts and studies the functions of each apart from the others.

THE FURNACE AND BOILER.

Any steam-generating apparatus consists essentially of two parts—the furnace and the boiler. Each of these two parts has definite functions, which it performs with a certain completeness or efficiency. The functions of the two parts are very different in character; that of the furnace is to liberate the potential energy of the fuel and that of the boiler to absorb the heat which the furnace has liberated. The furnace is the heat generator and the boiler the heat absorber. According to these statements the furnace can be defined as the part (or parts) of the steam-generating apparatus that changes the potential energy of the fuel into heat. Thus the grate or stoker, the combustion space, the gas-mixing structure, or any other part of the apparatus that aids in the combustion of the fuel is a part of the furnace. The boiler is the iron vessel that contains the water and the steam, and absorbs the heat liberated by the furnace. The boiler can not receive any of the potential energy from the fuel unless this energy is first changed into heat. Therefore the efficiency of the steam-generating apparatus depends directly on how completely the furnace changes the potential energy of the fuel into heat; in other words, how completely the furnace burns the fuel.

FURNACE AND BOILER EFFICIENCIES.

From the above statement of the function of the furnace, the furnace efficiency might be defined as the ratio of the heat developed in the furnace to the heat value of the fuel burned. This, however, would not be a logical definition of the furnace efficiency, as will be shown later, and therefore this ratio is called the percentage of completeness of combustion.

Similarly the boiler efficiency might be defined as the ratio of the heat absorbed by the boiler to the heat evolved in the furnace. This definition, however, is not fair to the boiler, inasmuch as it does not give the ability of the boiler to absorb the heat, but merely shows how much of the heat developed in the furnace was utilized in making

steam. One may, therefore, call it the percentage of completeness of heat utilization.

When the completeness of combustion and the completeness of heat utilization are multiplied together, both being expressed as percentages, the product is the over-all efficiency of the steam-generating apparatus.

After the heat has been liberated from the fuel it is contained partly in hot, burning fuel, but mostly in the gaseous products of combustion. From the hot fuel the heat is radiated to the boiler and to other surrounding colder objects. The gaseous products of combustion pass over the heating plates of the boiler and impart heat to them. Now, as heat flows from any hot body only to bodies at lower temperatures, the heating plates of the boiler can absorb only that part of the heat in the gases which is at higher temperature than the plates themselves. In other words, the boiler at the best can cool the gases only to its own temperature. Inasmuch as boilers are operated at temperatures ranging from 325° to 425° F., and higher, a considerable quantity of the heat in the gases may be below the temperature of the boiler and therefore not available for absorption, reducing by the same amount the quantity of heat that the boiler can absorb. It is reasonable to expect that, when the quantity of heat available for the boiler is smaller, the latter will absorb proportionately a smaller quantity, and that consequently the over-all efficiency of the steam-generating apparatus will be lower.

The quantity of heat that is not available for absorption on account of being below the temperature of the heating plates of the boiler increases directly with the weight of the products of combustion per pound of combustible, and this weight in turn increases almost directly with the air supply. The nature of the process of heat generation is such that part of the heat generated is necessarily below the temperature of the boiler plates; however, this part of the unavailable heat should be made as small as practicable by reducing the air supply. It is apparent that if the boiler is to receive any of the heat stored in the coal this heat must be not only first developed in the furnace, but it must be delivered to the boiler at sufficiently high temperature to flow into the boiler plates. This latter requirement is another factor entering into the effectiveness of the furnace. Thus it can be seen that there are two factors governing the effectiveness or the efficiency of the furnace, namely, completeness of combustion and high temperature. We can have absolutely complete combustion, but if the weight of the products of combustion is so large that the resulting temperature is low the greater part of the heat may be below the temperature of the boiler and only a small quantity may be available for absorption. On the other hand, the air supply may be so reduced that a large part of the heat in the

fuel will not be developed and therefore will not be available for the boiler. Thus, although the quantity of heat below the temperature of the boiler is small, the total heat developed by the combustion is so reduced that only a comparatively small quantity of the potential heat in the coal is made available for the boiler, and therefore a proportionately smaller quantity is absorbed by it. It is difficult to define the efficiency of the furnace so that both of the factors may be correctly included and at the same time make the definition applicable to all steam pressures.

Perhaps the furnace efficiency would be most logically defined as the ratio of the heat made available for the boiler to the potential heat in the fuel used up by the furnace. The heat available for the boiler is that portion of the heat in the gases that would have to be abstracted to bring their temperature down to the temperature of the steam in the boiler. The furnace efficiency just defined would never reach unity unless the fuel and the air necessary for combustion were delivered to the furnace at the temperature of the boiler water. Such an efficiency statement, however, indicates the relative effectiveness of the furnace with fair accuracy when the steam pressure is constant. With variable steam pressures the same furnace performance would be expressed by varying figures.

A boiler efficiency corresponding to that of the furnace efficiency discussed in the preceding paragraph can be defined as the ratio of the heat absorbed by the boiler to the heat available for absorption. This boiler efficiency is the true measure of the capacity of the boiler to absorb heat. It has been defined in United States Geological Survey Bulletin No. 325 and in Bureau of Mines Bulletin No. 18, (in course of publication) and called the true boiler efficiency. The true boiler efficiency multiplied by the furnace efficiency gives the over-all efficiency of the steam-generating apparatus.

The furnace may be further subdivided into its parts and the function and the efficiency of each of the parts separately defined. Thus we can resolve the furnace into the grate and the combustion space.

The grate is the metallic structure supporting the fuel bed. Its function, besides the holding of the fuel bed, seems to be to gasify the combustible of tne fuel either by complete or partial combustion and to allow the ashes to fall through after the combustible has been burned from the fuel. The efficiency of the grate may be defined as the ratio of the heat of the combustible ascending into the combustion space, in whatever form, to the heat of the fuel fired upon the grate. The difference between these two heats is the heat value of the combustible that has fallen through the grate or has been removed with the clinkers through the furnace door. The combustible lost in the ashes or clinker reduces the efficiency of the grate. A grate

with 100 per cent efficiency would be one that would allow the ashes to fall through without allowing any combustible to fall through with them.

The combustion space of a boiler furnace is all the space above the fuel bed and continues back of the bridge wall to the place where the gases enter the boiler; it includes the tile roof, ignition arches, and all the gas-mixing structures. Its function is to burn the combustible ascending from the grate in whatever form it may be. The gases leaving the fuel bed are rich in combustible gas, particularly in the case of the hand-fired furnace, as shown by the gas analyses on page 282, so that most of the combustion of the fuel occurs in the space after air has been added to the gases. The efficiency of the combustion space may be defined as the ratio of the heat made available for the boiler to the heat equivalent of the combustible ascending from the grate.

Further subdivision of the furnace and boiler parts and the defining of their efficiency would have hardly any practical or scientific value. The following efficiencies have been defined:

(*a*) Over-all efficiency of the steam-generating apparatus=

$$\frac{\text{Heat absorbed by the boiler}}{\text{Heat value of coal fired upon the grate}}$$

(*b*) Percentage of completeness of combustion=

$$\frac{\text{Heat developed in the furnace}}{\text{Heat value of coal fired upon the grate}}$$

(*c*) Percentage of completeness of heat utilization=

$$\frac{\text{Heat absorbed by the boiler}}{\text{Heat developed in the furnace}}$$

(*d*) Furnace efficiency=

$$\frac{\text{Heat made available for absorption by the boiler}}{\text{Heat value of coal fired upon the grate}}$$

(*e*) Efficiency of grate=

$$\frac{\text{Heat value of combustible ascending from the grate}}{\text{Heat value of coal fired upon the grate}}$$

(*f*) Efficiency of combustion space=

$$\frac{\text{Heat made available for absorption by the boiler}}{\text{Heat value of combustible ascending from the grate}}$$

(*g*) True boiler efficiency=

$$\frac{\text{Heat absorbed by the boiler}}{\text{Heat available for absorption by the boiler}}$$

Of these six ratios, those given under (*a*), (*d*), and (*g*) are perhaps the most important. Only those given under (*a*) and (*e*) can be obtained accurately; the others can be found only approximately. By multiplying or dividing these ratios various combinations can be obtained; thus

$$(d) = (e) \times (f);$$
$$(a) = (e) \times (f) \times (g);$$
$$(a) = (b) \times (c);$$
$$(f) \times (g) = \frac{(a)}{(e)}.$$

The last ratio is given in Table 4, in columns 80 and 81, where it is denoted as efficiency of the boiler. This notation has been given to it in accordance with the code of the American Society of Mechanical Engineers, although in reality it is the combined efficiency of the combustion space and the boiler. The ratio under (*a*), which has been called the over-all efficiency of the steam-generating apparatus, is given in column 82 of Table 4, where it is denoted as efficiency of boiler, including grate. The efficiency of the grate can be obtained by dividing column 82 by column 81. For most of the tests the other efficiencies above defined can be computed approximately from analyses of the flue gas and the coal, the heat value of the coal burned, the total heat absorbed by the boiler, and the temperature of the flue gases.

RELATIONS OF TEST DATA TO RESULTS OF TESTS.

This chapter is partly a study of the relations between the observed test data themselves, but mostly a study of the computed economic results as affected by the variation of the more important data. The study is chiefly made by means of curves made by platting the averages of one set of observations against some other set of observations or against the computed results. In some charts the averages of the individual tests are platted directly, but in most cases these averages are classified in groups and the average of the whole group is platted against similar averages of some other data of the group. The discussion and charts are intended to show general relations to which, of course, there are necessarily some exceptions. However, it is perhaps the establishment of these general relations that has the most permanent value for the practical engineer.

The capacity and the efficiency are the most important items of steaming tests, because they are the measure of the output and the economy of a steaming apparatus. Naturally one's first questions are: How much work can a certain device do? and, At what cost does the device do the work? Therefore, the study of the steaming tests centers about these two items—capacity and efficiency. Other

items are studied only with the object of obtaining information as to why the capacity or efficiency is high or low. If the causes of low results are known, these causes can be removed and the results improved. In a study of the present series of steaming tests one has these three questions to guide him: How much work is done? How well is it done? and, Why is it done well or poorly?

EFFECT OF RATE OF COMBUSTION ON RESULTS OF TESTS.

EFFECT OF RATE OF COMBUSTION ON THE CAPACITY AND EFFICIENCY OF STEAM-GENERATING APPARATUS.

It is an every-day experience that an increase in the rate of combustion increases the capacity of a boiler, although not quite in the same proportion, inasmuch as the efficiency of the steam-generating apparatus drops somewhat. That such relations should exist is obvious. When more coal is burned in the furnace, more heat is evolved and delivered to the boiler, and the latter absorbs a larger quantity of heat. At the same time, however, when the combustion space is burning an increasing quantity of gaseous combustible, the percentage of completeness of combustion is becoming less. The boiler has also more heat to absorb, with the result that it does this somewhat less completely. For these reasons the efficiency of the steam-generating apparatus drops slightly when the rate of combustion increases.

How the rate of combustion affects the capacity and the efficiency is shown in figure 17.

In the preparation of this figure only tests made on boilers Nos. 1 and 2 were used, inasmuch as these two boilers were very nearly alike and the conditions under which the tests were made were the same. The tests were classified into groups according to rate of combustion. Thus the tests with a rate of combustion between 14 and 15 pounds per hour were all put into one group, tests with a rate of combustion between 15 and 16 pounds per hour into another group, and so on until the entire range of rate of combustion was covered. The capacities and the efficiencies of each group were averaged and these averages (arithmetic) were platted against the rate of combustion that each group represented. Through the points thus obtained a smooth curve was drawn. The figures in the circles representing the capacity points indicate the number of tests contained in each group. The same method as here described was employed in the preparation of all other charts in which the tests are arranged in groups.

The efficiency used in the compilation of this and most of the other charts in this bulletin is the combined efficiency of the combustion space and the boiler and not the over-all efficiency. It is the efficiency given in column 81 of Table 4, and does not take into account the

effect of the grate. In the code of the American Society of Mechanical Engineers it is designated as the "efficiency of boiler." The reason for selecting this value rather than the over-all efficiency given in column 82 is that the two boilers were equipped with different grates, and therefore it was thought best to eliminate the effect of the grate when comparing efficiency.

The upper curve of figure 17 shows that the capacity rises as the rate of combustion increases, although not in the same proportion. Thus when the rate of combustion is 16 pounds per hour the capacity

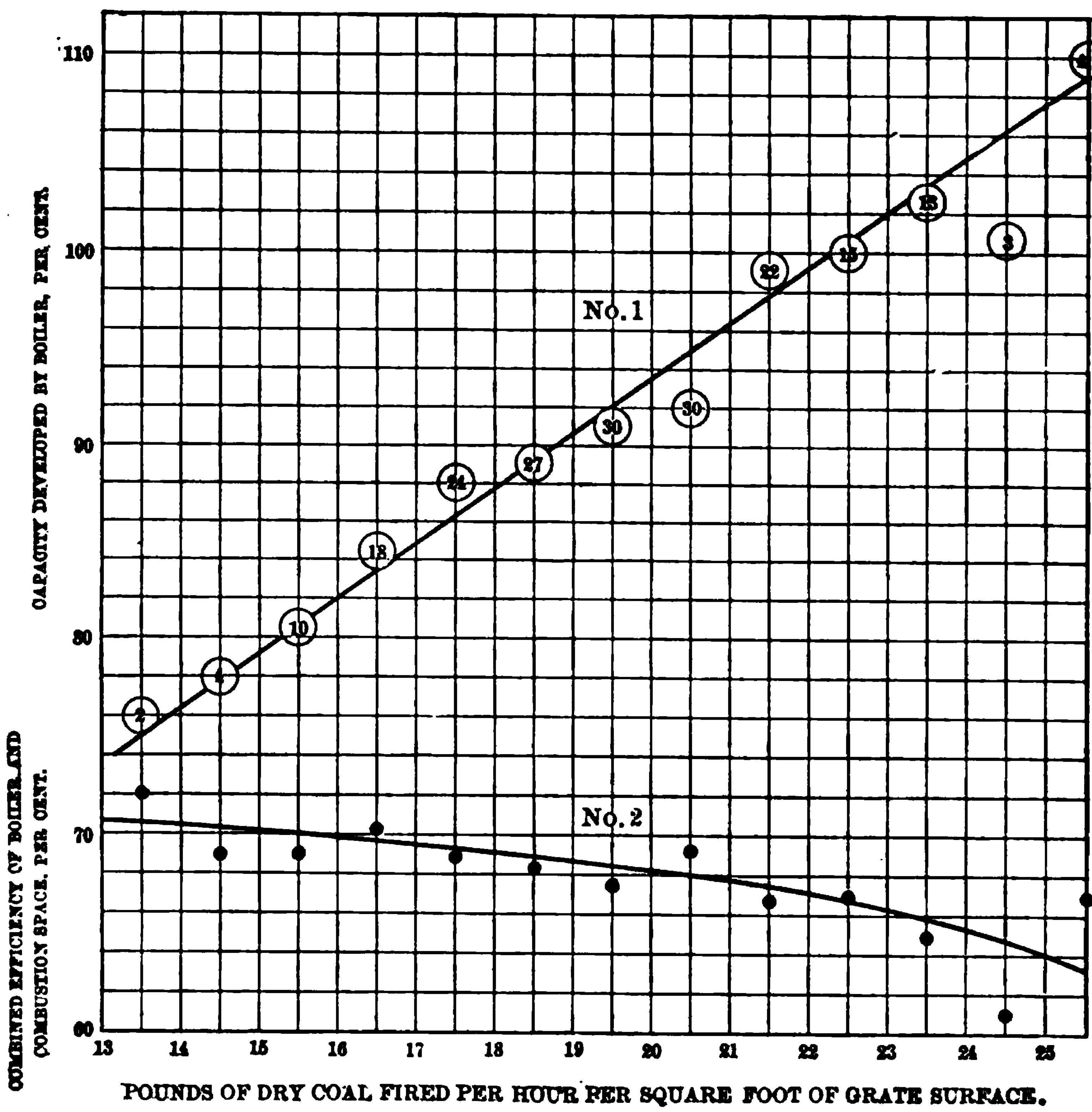


FIGURE 17.—Curves showing the effect of rate of combustion on the capacity and efficiency of steam-generating apparatus. Curve No. 1 shows the effect on capacity and curve No. 2 shows the effect on efficiency. Tests made on boilers Nos. 1 and 2.

is about 82 per cent, and when the rate of combustion is 24 pounds per hour the capacity is 105 per cent, whereas it would be 123 per cent if it increased in proportion to the rate of combustion. The failure of the capacity to keep up with the rate of combustion is not due entirely to the drop in efficiency of the apparatus. As shown in the lower curve, the same increase in the rate of combustion causes the efficiency to drop from 70 to 65.4 per cent, or only about 4.5 per cent, which is not sufficient to account for the shortage in the capacity. Undoubtedly the main cause of the capacity not being more nearly

proportional to the rate of combustion is the fact that coals of high heating value are usually high in fixed carbon, and on that account are slow burning. Therefore these coals predominate at the left of the chart, whereas the low-grade western coals, which burn very quickly, predominate at the right of the chart. This fact may also cause the efficiency curve to drop more with the rate of combustion than it would if all the tests were made with the same coal. As suggested at the outset of this discussion, the drop in efficiency at the right of figure 17 is due to two causes, namely, incomplete combustion of the combustible in the combustion space, and incomplete heat absorption by the boiler. These two causes are discussed more fully in connection with figures 37, 38, 39, 40, and 44, and also under the headings on the fundamental principles of combustion and of heat transmission.

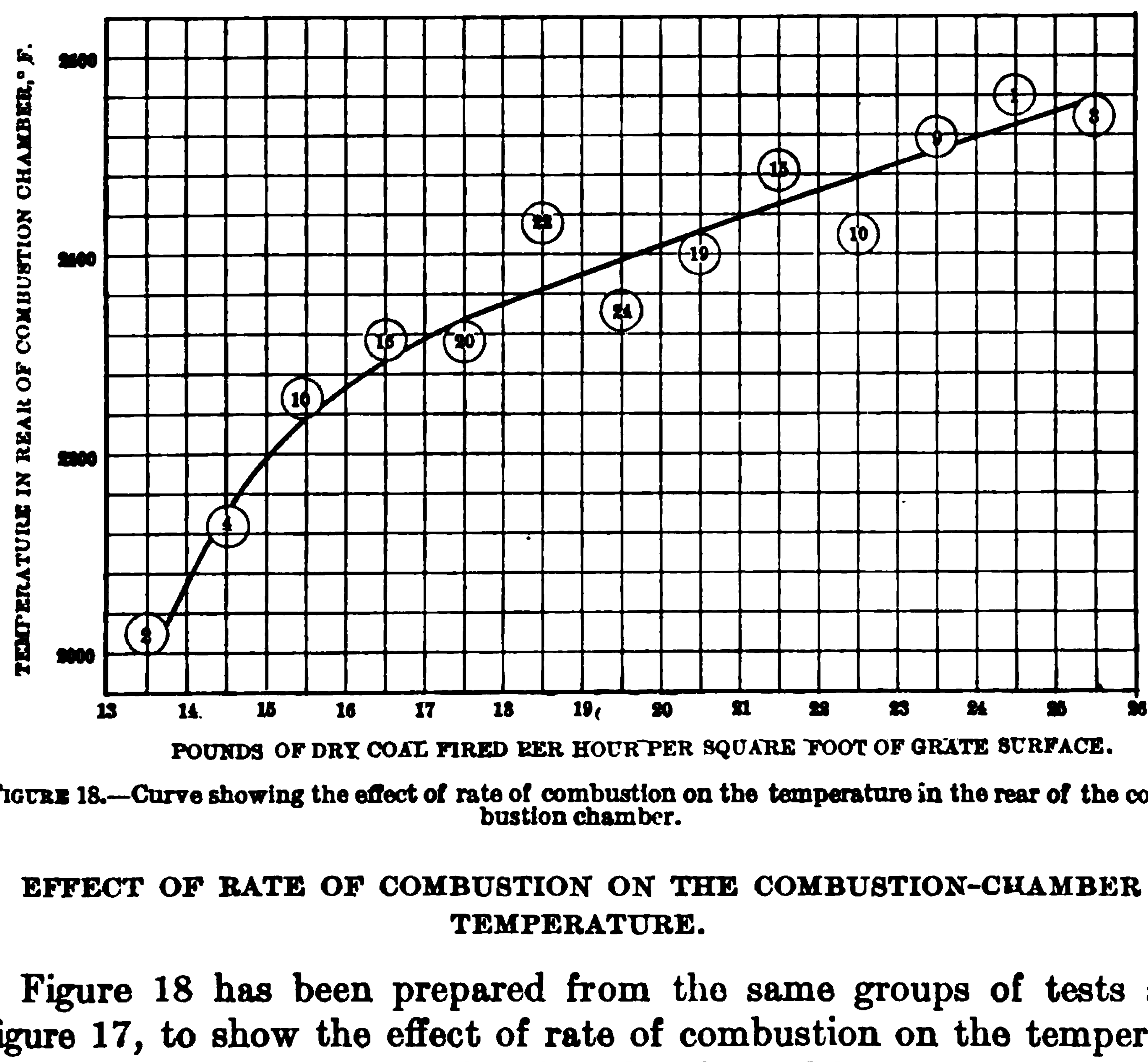


FIGURE 18.—Curve showing the effect of rate of combustion on the temperature in the rear of the combustion chamber.

EFFECT OF RATE OF COMBUSTION ON THE COMBUSTION-CHAMBER TEMPERATURE.

Figure 18 has been prepared from the same groups of tests as figure 17, to show the effect of rate of combustion on the temperature in the rear of the combustion chamber. The temperature was measured near the point where the products of combustion enter the space among the tubes of the boiler. It would seem that the tile roof of the furnace prevents the abstraction of heat from the gases before the latter reach this point and that their temperature at this point should be the initial temperature resulting from the combustion of the fuel. If such were the case the temperature in the rear of the combustion chamber would depend only on the air supply, the heat value of the fuel, and the specific heat of the products of combustion;

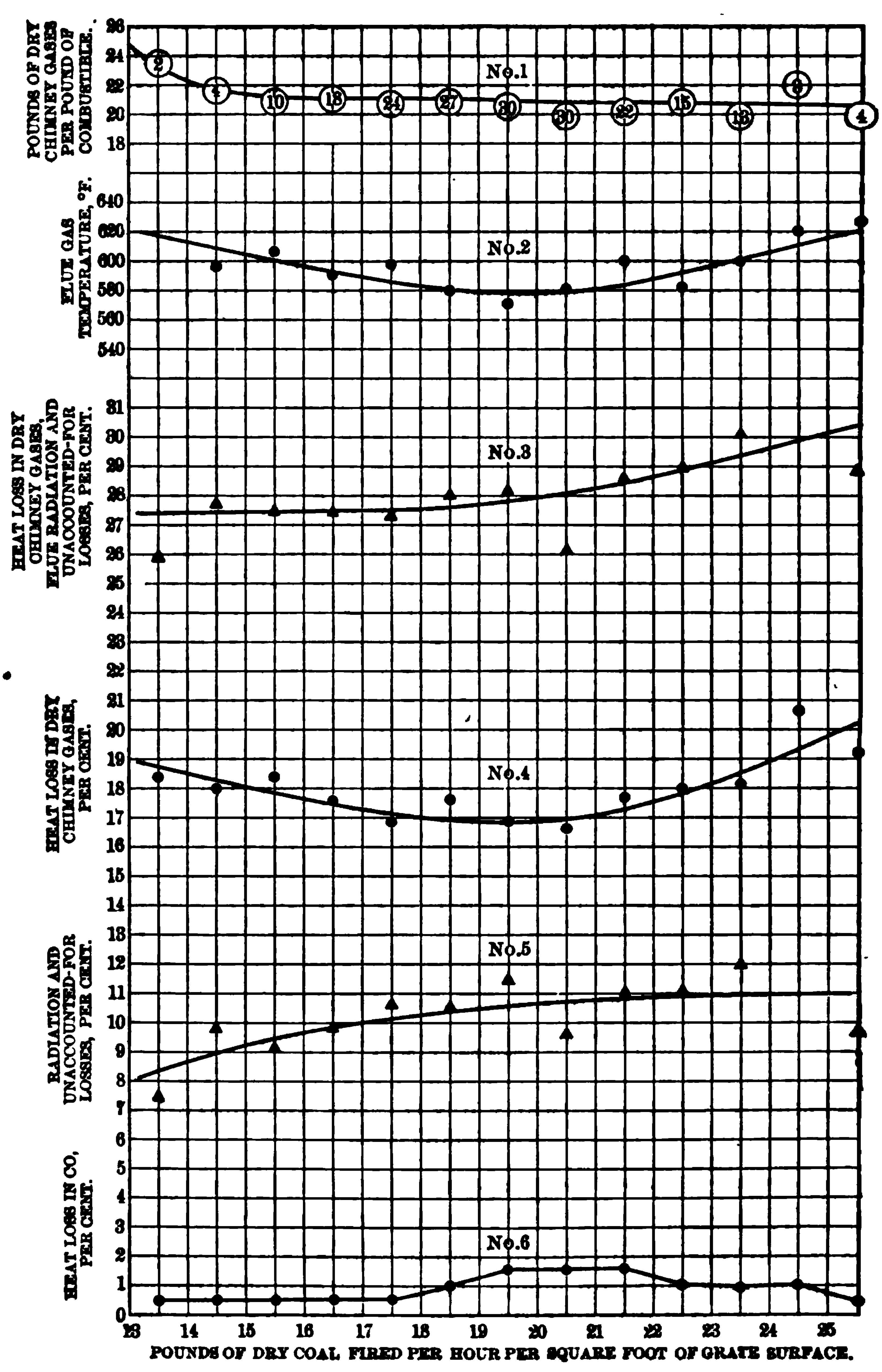


FIGURE 19.—Curves showing the effect of rate of combustion on: Pounds of dry chimney gases per pound of "combustible" (No. 1); flue-gas temperature (No. 2); heat loss in dry chimney gases plus radiation and unaccounted-for losses (No. 3); heat loss in dry chimney gases (No. 4); radiation and unaccounted-for losses (No. 5); heat loss in CO (No. 6).

in other words, it would vary only with the air supply and the nature of the coal. However, numerous observations of the temperature have shown that the latter varies considerably with the rate of combustion. Figure 18 also shows that the combustion-chamber temperature rises decidedly with the increasing rate of combustion, notwithstanding the fact that the better coals may predominate at the left of the figure, which would tend to raise the temperature at the low rates of combustion.

Although the furnace roof is made of tiles of fire clay, a material that is a poor conductor of heat, the path of the products of combustion along the roof is so long that considerable heat is abstracted from the gases by the tile roof before they reach the tubes of the boiler. Now, since the good coals are high in fixed carbon they burn almost completely on the grate, so that, although the temperature of the products of combustion near the grate may be high, by the time the gases reach the rear of the combustion chamber their temperature is reduced considerably by the abstraction of heat by the tile roof. On the other hand, most of the low-grade coals are high in volatile combustible, which burns in the combustion space after it has left the fuel bed, so that the combustion is completed farther away from the grate and nearer to the combustion chamber. On account of the shorter path of the gases to the place where the temperature is measured less heat is abstracted from them, and consequently their temperature is higher when they pass among the boiler tubes. It is obvious that, since at higher rates of combustion more volatile combustible is distilled from the fuel bed and has to be burnt in the combustion space, the point of complete combustion moves nearer the rear of the combustion chamber and raises the temperature at that point. Complete combustion here does not mean the absolute oxidation of all the combustible, as this is really never attained; it means rather the conditions following the very active combustion resulting from the admixture of air with the volatile combustible. The rate of combustion may be so increased that very active combustion of the volatile matter may take place in the rear of the combustion chamber, in which case the temperature at that place would be at its maximum. If the rate of combustion was still further increased some of the volatile combustible would pass out of the furnace unburnt. Thus we can see why, in general, the combustion-chamber temperature rises when the rate of combustion increases.

EFFECT OF RATE OF COMBUSTION ON AIR SUPPLY, FLUE-GAS TEMPERATURE, AND THE ITEMS OF THE HEAT BALANCE.

Figure 19 has been prepared in the attempt to find the causes of the efficiency drop shown in figure 17. The figure shows the effect of the rate of combustion on the weight of air used in burning the

fuel, the flue-gas temperature, and the three most important heat losses in the heat balance. This figure was prepared in the same way and the same tests were used as in the preparation of figure 17. The showing of figure 19 is not definite, due undoubtedly to the fact that the coals tested were of very different characters. Then, too, the range of the rate of combustion is not wide enough to make the effects apparent. The failure of this figure emphasizes the fact that when it is desired to investigate the effect of one factor the tests should be so selected as to eliminate other variables. The following statement can be made, however, in connection with this figure:

Curve No. 1 shows that as the rate of combustion increases the weight of air used to burn 1 pound of combustible remains nearly constant, or, if anything, it decreases a little. This decrease is probably due to the fact that with higher rates of combustion the air leakage into the setting is less in proportion to the air entering the furnace through the burning fuel bed. At the left of the curve coals predominate which were hard to burn and consequently high drafts had to be carried, which naturally tended to increase the leakage.

Curve No. 2 shows that as the rate of combustion increases the flue-gas temperature drops at first and then rises. The rise in the temperature at the right of the curve may be accounted for by the rise in the combustion-chamber temperature as shown in figure 18. There does not seem to be any satisfactory explanation for the drop at the left of the curve. Any speculation on this point would be of doubtful value, inasmuch as the whole range of the flue-gas temperature is only about 50° F.

Curve No. 4 shows that as the rate of combustion increases the heat loss in the dry chimney gases at first drops slowly about 2 per cent and then rises somewhat faster. The drop at the left of the curve is obviously caused by the decreasing air supply and the flue-gas temperature as shown by curves Nos. 1 and 2, respectively. The rise at the right of the curve is due to the rising flue-gas temperature.

Curve No. 5 shows that the "unaccounted-for" rises with the rate of combustion, but that the rise is small and therefore not decisive. The unaccounted-for contains the heat lost in the escape of the unburnt hydrocarbons. When the rate of combustion increases one would expect larger quantities of these hydrocarbons to escape unconsumed, and therefore the unaccounted-for heat loss to rise.

Curve No. 6 shows that, in general, the heat loss due to the escape of unburnt CO increases with the rate of combustion. The increase in the heat loss due to this cause must, of course, be expected; when more work is required of the furnace the latter does not perform its functions with the same completeness as when operated at lower capacity, and hence the increased loss in CO.

EFFECT OF RATE OF HEAT EVOLUTION ON CAPACITY AND EFFICIENCY.

It has been stated in connection with figures 17, 18, and 19 that the effect of the rate of combustion upon the various items was not definite because the tests used in the compilation of those charts were made on coals greatly varying in character. That is, tests made on coals having a heat value of 15,000 B. t. u. per pound of dry coal were used along with tests made on coals running only 11,000 B. t. u. per pound of dry coal. On account of these widely differing coals predominating in the various parts of the curves, the effect of the rate of combustion was largely destroyed. To eliminate this objection the same tests were classified into groups on the basis of the rate of heat evolution in the furnace. The arithmetic averages of the results and of some of the data of each group were obtained and platted against the rate of heat evolution. The curves thus obtained are given in figures 20, 21, and 22. The classification of the tests on the basis of the heat presumably evolved will show approximately the same effects as the classification on the rate of combustion of tests made with coals having the same heating value. The heat presumably evolved was taken as the heat value of the combustible ascending from the grate, and was figured as indicated by the following equation in which the column numbers refers to Table 4:

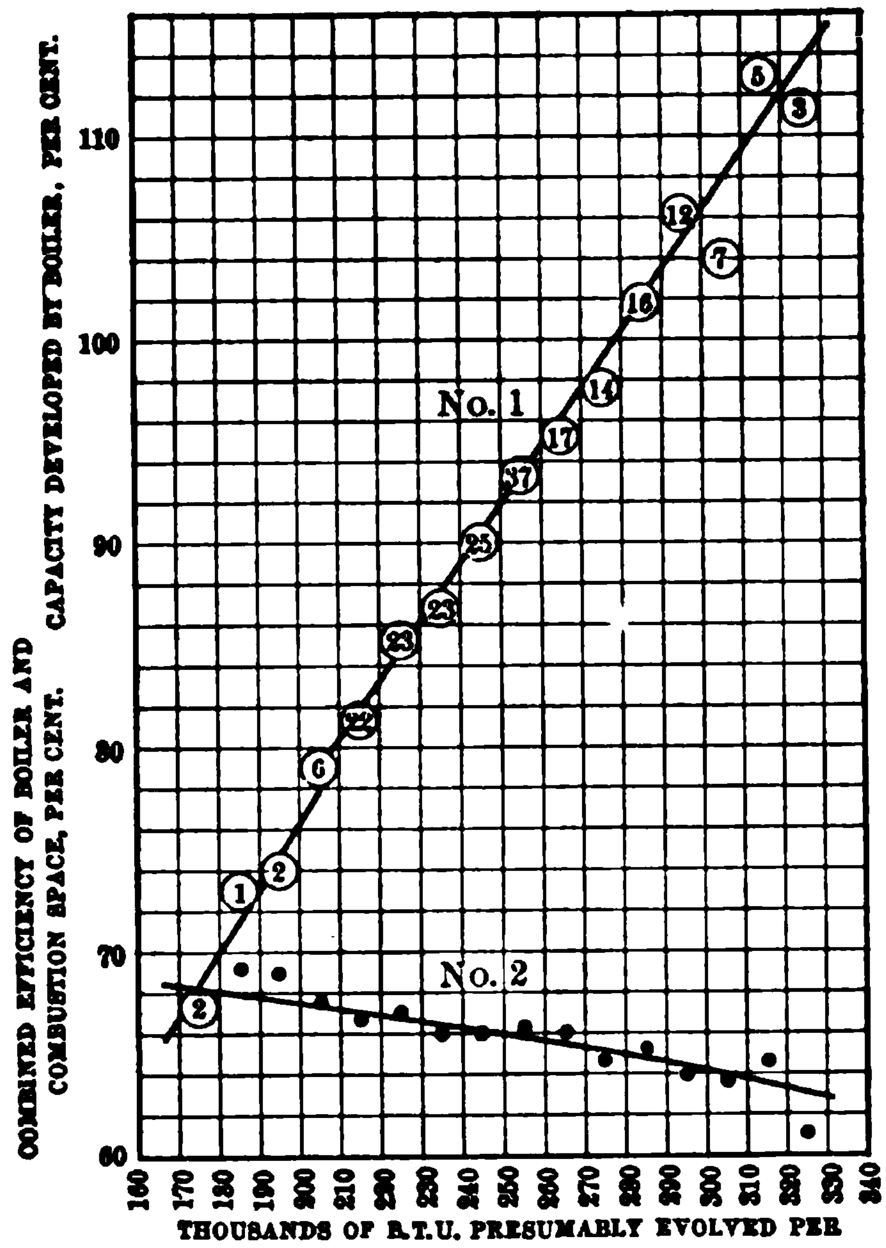


FIGURE 20.—Curves showing the effect of rate of heat evolution on the capacity and efficiency of steam-generating apparatus. Tests made on boilers Nos. 1 and 2.

Heat presumably evolved per square foot of grate area per hour=

$$\frac{\text{Column 54} \times \text{column 59}}{\text{Area of grate in square feet}}$$

Figure 20 is similar to figure 17. The increase of the capacity with the rate of heat evolution is more prominent than it is shown to be with the rate of combustion. The efficiency curve drops at about the same rate as it does in figure 17, and the drop can be ascribed to the same two causes, namely, less complete combustion of fuel and less complete absorption of the heat evolved.

EFFECT OF RATE OF HEAT EVOLUTION ON COMBUSTION-CHAMBER TEMPERATURE.

Figure 21 shows the effect of the rate of heat evolution on the combustion-chamber temperature; it is similar to figure 18. On comparing the two figures it can be seen that the combustion-chamber temperature rises somewhat more rapidly with the rate of heat evolution than with the mere rate of combustion. This more rapid rise in

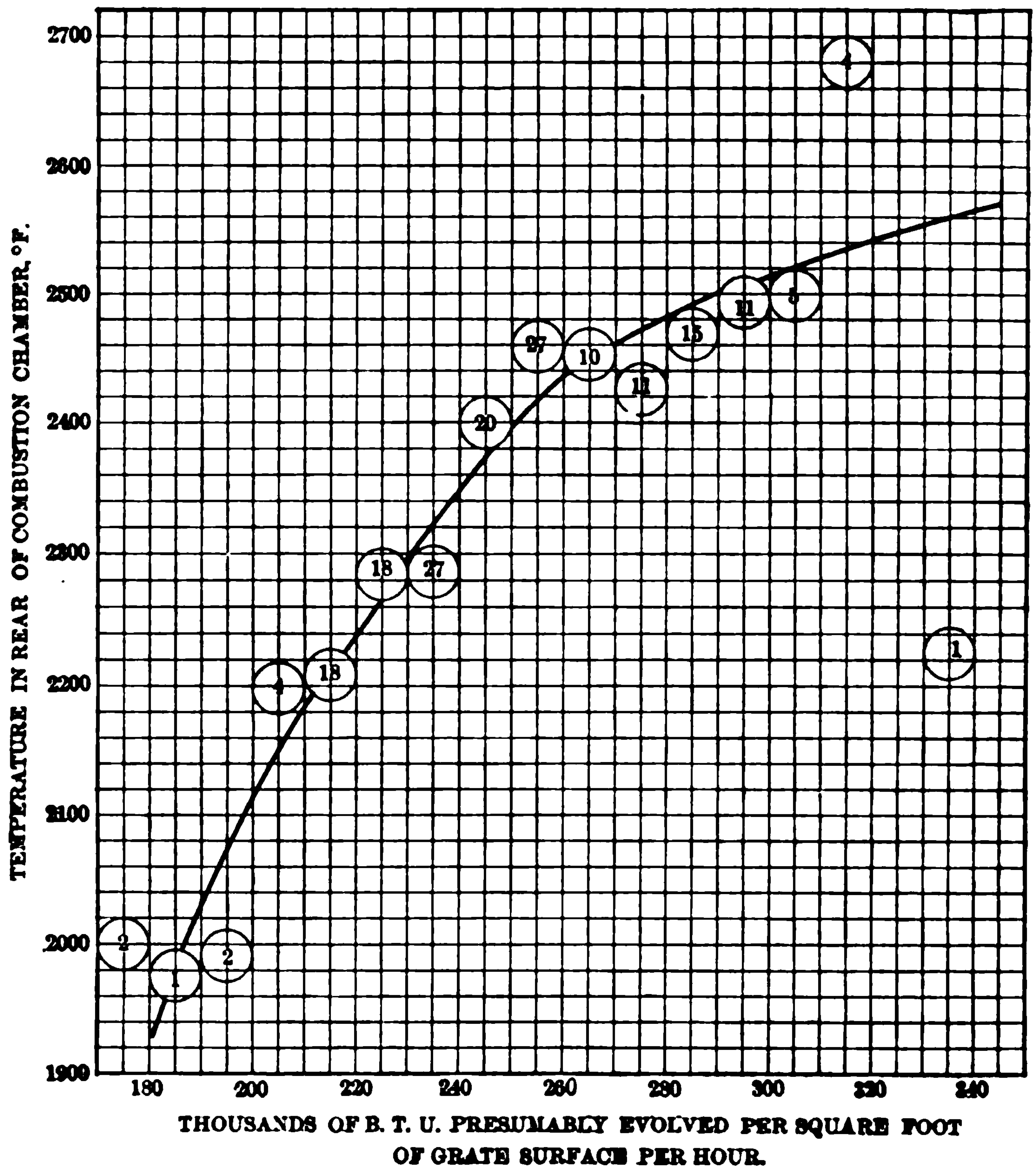


FIGURE 21.—Curve showing the effect of rate of heat evolution on the combustion-chamber temperature. Tests made on boilers Nos. 1 and 2.

the temperature is due to the fact that the inequality of the heating value of the coals has been eliminated, so that the coals low in heat value can not lower the points at the right of the figure.

In most of the coals low heating value is caused by the presence of a large quantity of ash and other noncombustible matter. If all the coals were reduced to combustible which is really available for burning, the heating values of 1 pound of each of such combustibles would be much closer together than those of the dry coals. Classifications based on the rate of combustion of such combustible would show

nearly the same effect on the results as the rate of heat evolution. It may be said that in general the quantity of heat evolved in the furnace is directly dependent on the quantity of such real combustible burned. This relation is the main reason why the combustion-chamber temperature rises when the quantity of the heat evolved increases. As stated in connection with figure 18, when the amount of combustible to be burned increases, the point of complete combustion recedes to the rear of the combustion chamber, and thus increases the temperature at that place.

EFFECT OF RATE OF HEAT EVOLUTION ON THE AIR SUPPLY, FLUE-GAS TEMPERATURE, AND ITEMS OF THE HEAT BALANCE.

Figure 22 is similar to figure 19. In the preparation of this figure the same tests were used as in figures 17, 19, and 20. The grouping of the tests was done on the basis of the rate of heat evolution.

In general, the effect of the rate of heat evolution upon the items investigated is much more apparent than is the effect of the rate of combustion upon the same items. As previously stated, this more marked effect of the rate of heat evolution is due to the elimination of the influence of the difference of the heat values of coals.

Curve No. 1 shows that as the rate of heat evolution increases the weight of the chimney gases per pound of combustible decreases at first, but when the rate of heat evolution is ahout 25,000 B. t. u. the weight of gases becomes constant at slightly less than 20 pounds. It is difficult to explain why the air supply should be high at the low rates of heat evolution. The large supply of air shown at the left of the curve is one cause of the low combustion-chamber temperature shown in figure 21.

Curve No. 2 indicates that the flue-gas temperature rises as the rate of heat evolution increases. This rise in the flue-gas temperature can be explained by the fact that the combustion-chamber temperature rises, as shown in figure 21. The fact that the flue-gas and the combustion-chamber temperatures rise and fall together is a well-proved relation and is more fully explained in the section on "Principles involved in heat transmission into steam boilers."

Curve No. 4 shows how the rate of heat evolution affects the loss of heat in the dry chimney gases. The high heat loss in the dry chimney gases shown at the left of the curve is obviously due to the large air supply shown by curve No. 1, and the high heat loss at the right is caused by the high flue-gas temperature shown by curve No. 2.

Curve No. 5 shows that the unaccounted-for item in the heat balance increases steadily with the rate of heat evolution. It has been stated that the quantity of heat evolved is nearly proportional to the quantity of the real combustible burned, so that a higher rate of heat evolu-

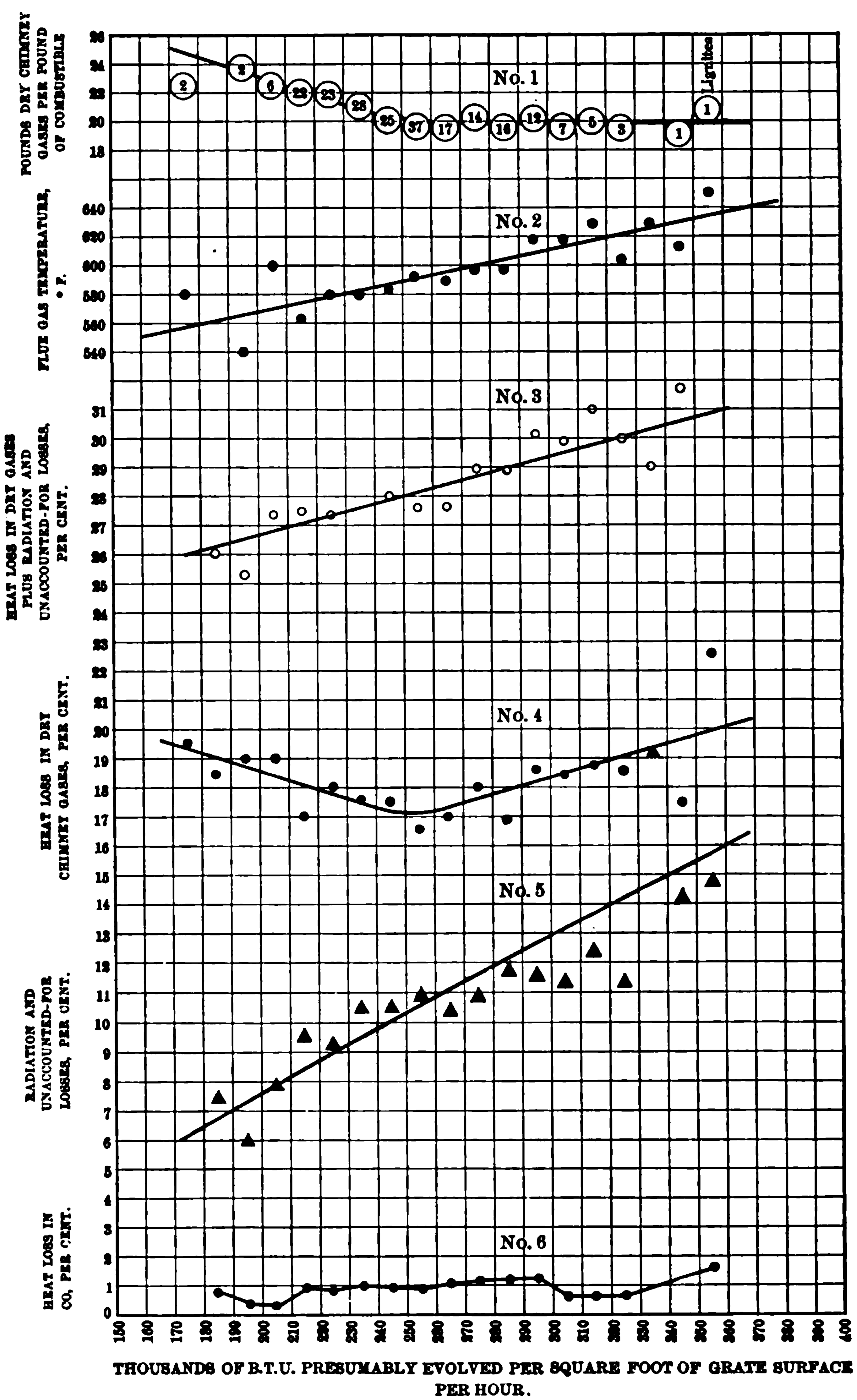


FIGURE 22.—Curves showing the effect of rate of heat evolution on: Pounds of dry chimney gases per pound of "combustible" (No. 1); flue-gas temperature (No. 2); heat loss in dry chimney gases plus unaccounted-for losses (No. 3); heat loss in dry chimney gases (No. 4); radiation and unaccounted-for losses (No. 5); heat loss in CO (No. 6). Heat losses are expressed as percentages of the total heat of the "combustible" ascending from the grate. Tests made on boilers Nos. 1 and 2.

tion is the result of a higher rate of burning of combustible. When the combustible is burned at higher rates its combustion is less complete. Therefore the rise of the unaccounted for at the right of the curve can be ascribed to the loss by incomplete combustion.

Curve No. 6 indicates that within the range investigated the rate of heat evolution has but little effect on the heat loss due to unburned CO. Generally this heat loss is small and varies considerably with the character of the coal, so that the effect of the rate of heat evolution on it may have been neutralized by changes in the character of coal.

Curve No. 3 gives the heat loss in the dry chimney gases and the unaccounted-for loss combined. The showing of the curve is a steady increase of the combined loss when the rate of heat evolution increases. This increase in the combined loss is nearly equal to the drop in the boiler efficiency curve as shown in figure 20.

EFFECT OF RATE OF COMBUSTION ON CAPACITY AND EFFICIENCY WHEN THE NATURE OF THE COAL REMAINS NEARLY CONSTANT.

The object of preparing the last six figures discussed was to study the effect of the rate of working of the furnace and the boiler upon the economic results. In the preparation of figures 17, 18, and 19 the grouping of tests was on the basis of the rate of burning dry coal, inasmuch as the rate of working the steam-generating apparatus depends directly, although not entirely, on how fast the coal is fired. The objection to these figures and their indications is that all tests made on boilers Nos. 1 and 2 were used in their compilation regardless of the heating value and the nature of the coal. Great variations in the heating value and the nature of the coal may add to or neutralize the effect of the rate of combustion; for that reason the indication of the three charts above named is not definite. The grouping of figures 20, 21, and 22 is based on the presumed heat evolution, and therefore the effect of varying heat value is eliminated from their indication; however, the effect of the nature of the coal remains, and the figures are open to objection on that account. To reduce the latter effect 75 tests, made with Illinois coals on boilers Nos. 1 and 2, were grouped on the basis of the "combustible" consumed per hour and figures 23 and 24 were platted. The two figures were prepared in the same manner as figures 17 and 19, or as figures 20 and 22, and show similar relations. It is known that the combustible bases of coals coming from this field have approximately the same heating values, and as the nature of the coals is nearly the same, the effect of these two variables in the last two figures is negligible.

It may be noticed in figure 23 that the points lie much closer to the smooth curves passed through them than in previous figures. The figure brings out much more definitely what has been indicated by figures 17 and 20. When the rate of combustion increases from

600 pounds to 900 pounds of combustible per hour, the capacity rises from 82 to 111 per cent, whereas it should rise to 123 per cent if the capacity were directly proportional to the rate of combustion. The capacity actually obtained is 12 per cent of the boiler's rating below what it should be, which is $\frac{12.0}{123} = 9.7$ per cent of the expected

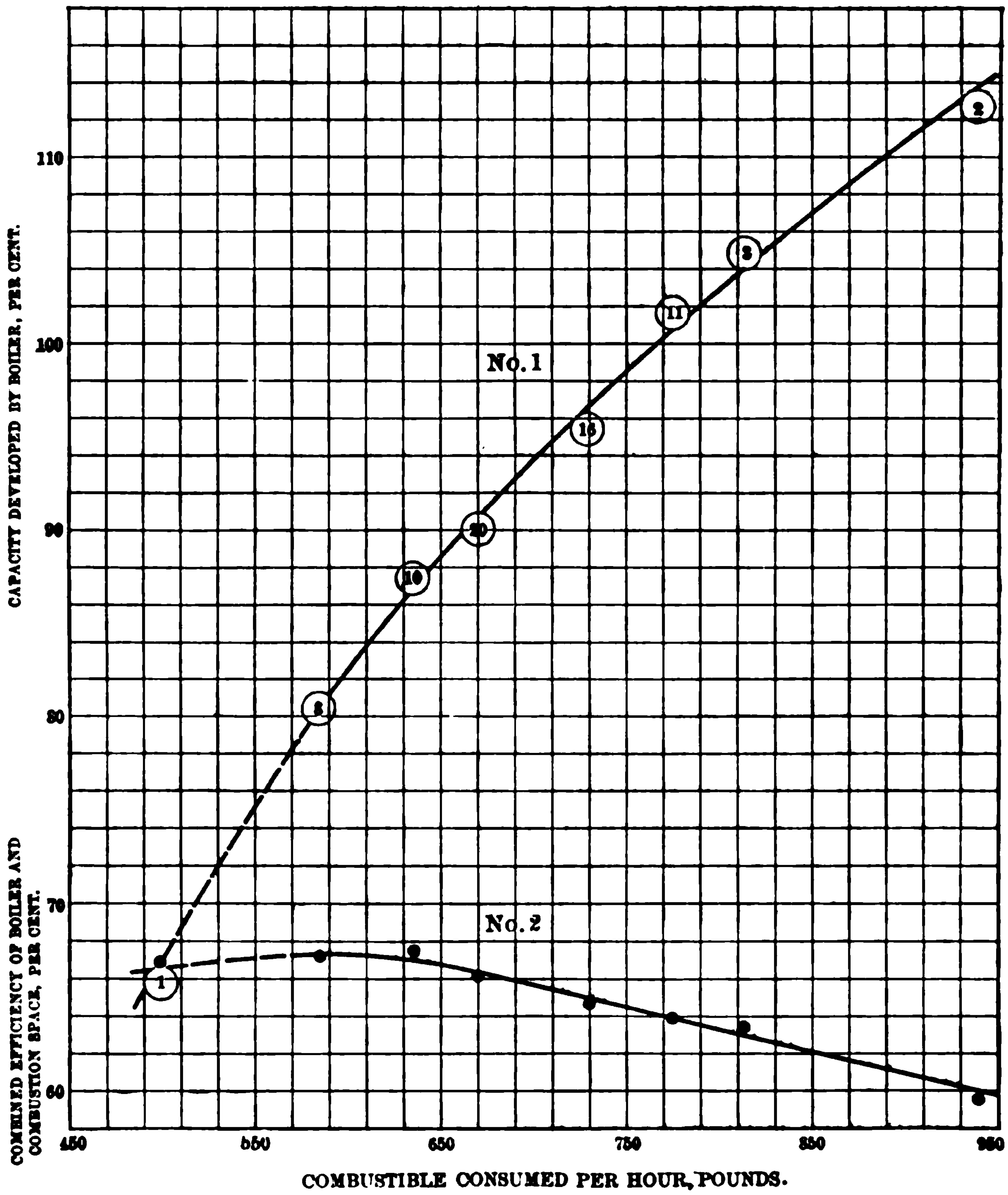


FIGURE 23.—Curves showing the effect of rate of combustion on capacity and efficiency when the heating value and the nature of the "combustible" remain nearly constant. Tests made on Illinois coals only.

capacity. For the same increase in the rate of combustion the efficiency drops from 67.5 to 61 per cent, which is $\frac{6.5}{67.5} = 9.7$ per cent of itself. The drop in the efficiency fully accounts for the shortage in the capacity at the higher rates of combustion. It has been already stated that the cause of the drop in the efficiency is less complete combustion of the fuel by the furnace and less complete absorption of the heat. This fact is brought out rather definitely by figure 24.

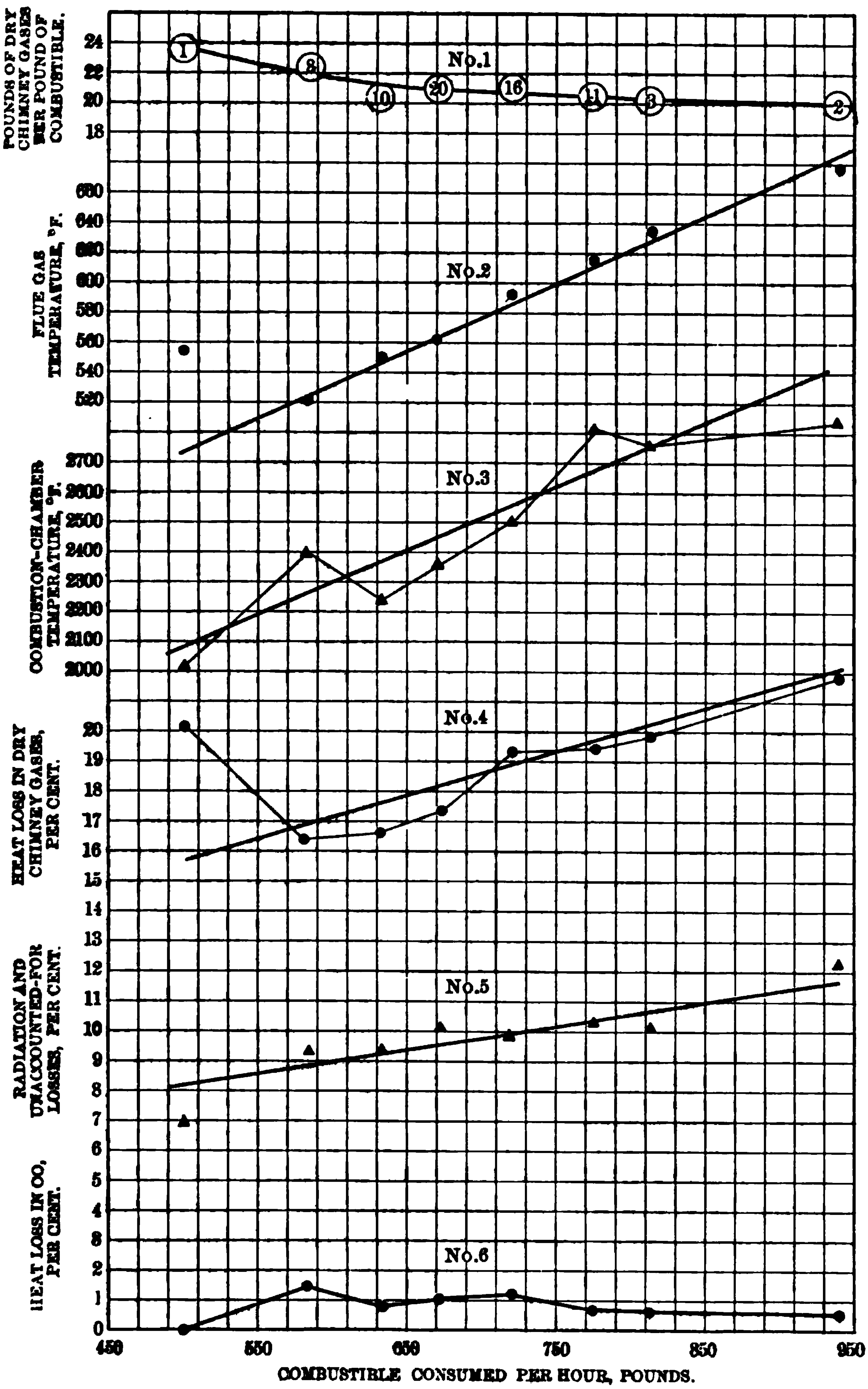


FIGURE 24.—Curves showing the effect of the rate of combustion on: Pounds of dry chimney gases per pound of "combustible" (No. 1); flue-gas temperature (No. 2); combustion-chamber temperature (No. 3) heat loss in dry chimney gases (No. 4); radiation and unaccounted-for losses (No. 5); heat loss in CO (No. 6) Tests made on Illinois coals only.

Curve No. 1 of figure 24 shows that as the rate of combustion increases the air supply diminishes. Generally speaking, the reduction in air supply will cause less complete combustion.

Curve No. 2 shows that the flue-gas temperature rises rapidly when the rate of combustion increases. Although a greater part of the rise of the flue-gas temperature may be justly attributed to the rise in the combustion-chamber temperature shown by curve No. 3, an appreciable part of the rise is the result of less complete absorption of heat by the boiler. That this is the cause is shown by the general slope of curve No. 4; this curve indicates that the loss of heat in the dry chimney gases increases with the rate of combustion although the weight of the gases per pound of combustible decreases.

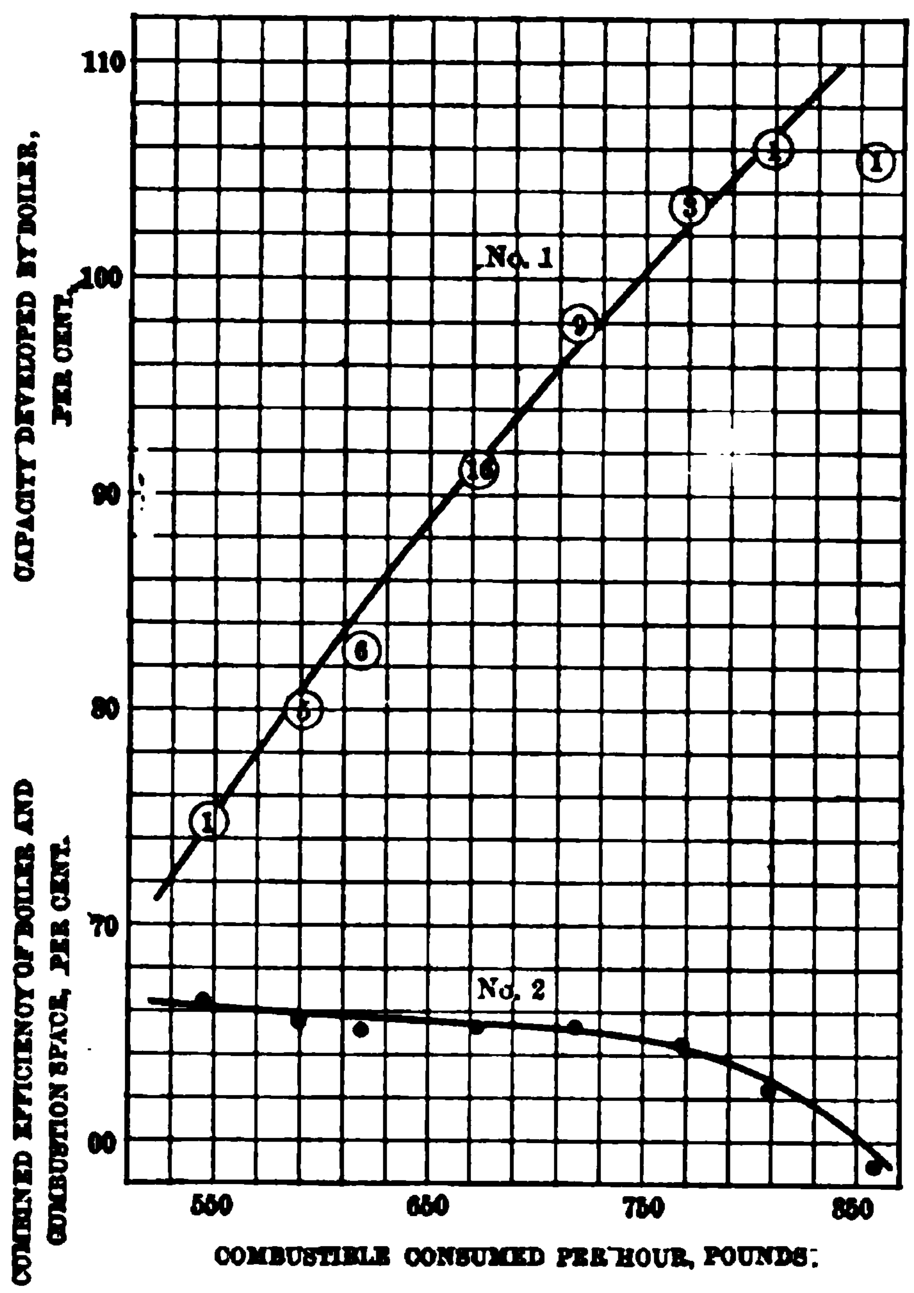


FIGURE 25.—Curves showing the effect of rate of combustion on capacity and efficiency when the heating value and the nature of the coal remain nearly constant. Tests made on Indiana coals only.

Curve No. 5 shows that the unaccounted-for losses increase as the rate of combustion increases. The two principal losses constituting this item are the radiation and the incomplete combustion of hydrocarbons which may exist in the flue gases either as gases, liquids, or solids. With constant boiler pressure the radiation from the boiler and setting is nearly a constant quantity of heat, so that the radiation loss decreases in percentage when the capacity increases. Therefore only the less complete combustion can explain the rise in curve No. 5.

The conclusion arrived at in the last paragraph does not seem to be supported by curve No. 6, which shows that in general with the tests investigated the heat loss due to unburned CO decreases as the rate of combustion increases. It would seem that the incompleteness of combustion would be indicated by the presence of CO, or, in other words, that the incompleteness of combustion would be proportional to the CO loss, but evidently the rule does not hold in all cases. It seems that as soon as one attempts to formulate any general rule numerous exceptions or modifications appear.

To further investigate the effect of the rate of combustion when the heat value and the nature of the coal remain nearly constant, tests made with Indiana coals were grouped according to the rate of com-

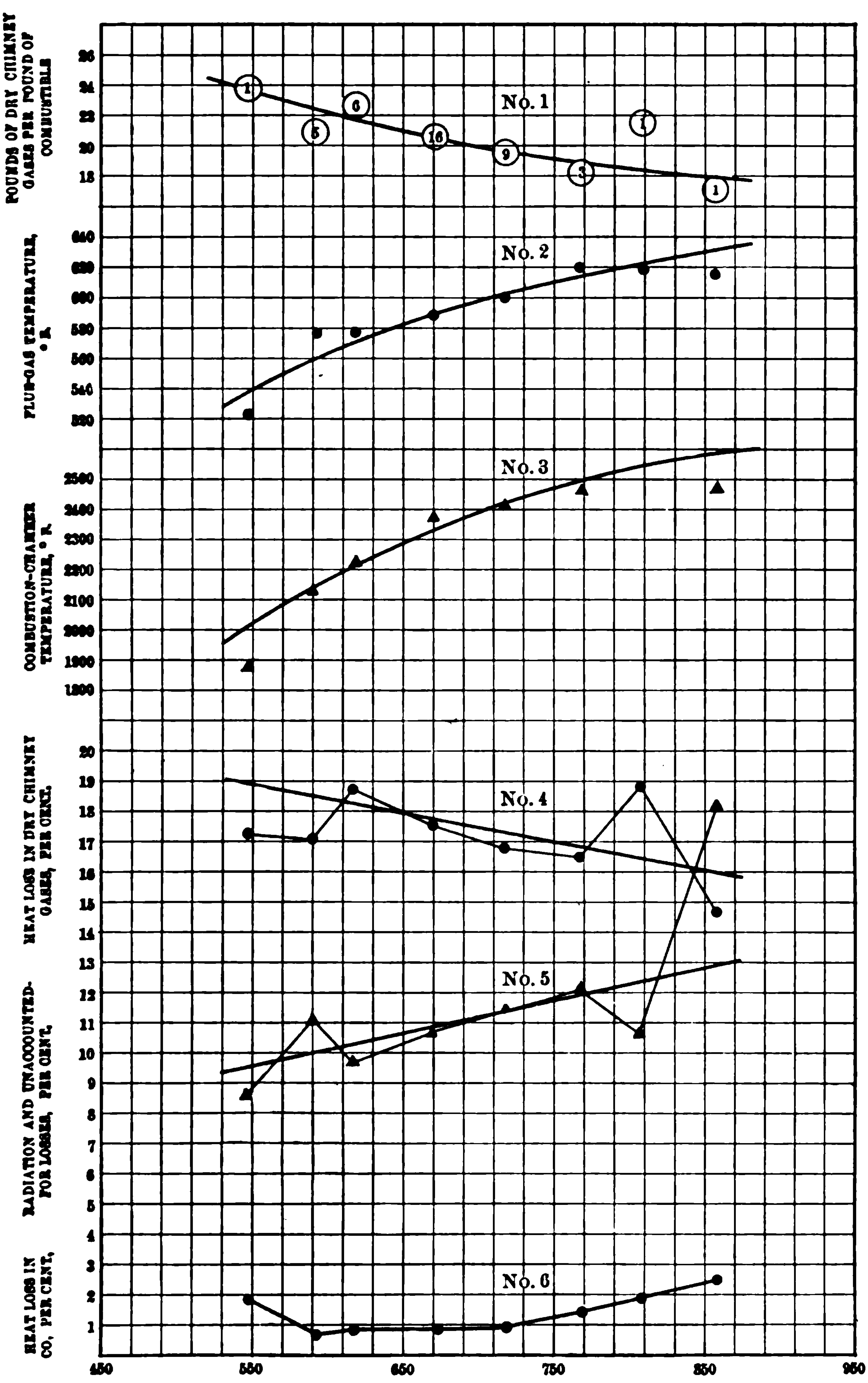


FIGURE 26.—Curves showing the effect of the rate of combustion on: Pounds of dry chimney gases per pound of "combustible" (No. 1); flue-gas temperature (No. 2); combustion-chamber temperature (No 3); heat loss in dry chimney gases (No. 4); radiation and unaccounted-for losses (No. 5); heat loss in CO (No. 6). Tests made on Indiana coals only.

bustion, and figures 25 and 26 were prepared. These two figures show the same relations for Indiana coals as figures 23 and 24 for Illinois coals.

An examination of figure 25 shows that the rise in capacity is more nearly proportional to the rate of combustion, and that the efficiency does not drop as much as shown in figure 23 for Illinois coals. The last two points of figure 25 should not be given much weight, inasmuch as each represents only one test.

The curves of figure 26 show several features that deserve to be mentioned.

Curve No. 1 shows that as the rate of combustion increases the air supply drops more rapidly and reaches lower limits with Indiana coal than it did with Illinois. This feature may account for the fact that the efficiency with the Indiana coal drops very little with the increase in the rate of combustion. Smaller air supply may have caused more heat to be available for the boiler, with the result that the latter absorbed nearly the same percentage of the heat of the combustible ascending from the grate.

The above reasoning seems to be supported by the indication of curve No. 4, which shows that notwithstanding the fact that the flue-gas temperature rises with the rate of combustion, the air supply drops so low that the heat carried away with the flue gas becomes less at the higher rate of combustion.

Curves Nos. 5 and 6 indicate less complete combustion at the right of the figure.

The apparent difference in the results of tests made on the Illinois and the Indiana coals is more likely due to the method of making the tests than to the slight difference in the nature of the two coals.

The various curves given in the last ten figures show that when the steam-generating apparatus is run at higher rates of working its efficiency drops somewhat, and that this drop in efficiency is due to less complete combustion of the combustible and less complete absorption of the heat available for the boiler. The physical and chemical reasons for these lessened effects are given with more detail in the two sections entitled "Principles involved in heat transmission into steam boilers" (pp. 340 to 361) and "Principles involved in the combustion of coal in boiler furnaces" (pp. 330 to 340).

COMPOSITION OF THE PRODUCTS OF COMBUSTION AND ITS EFFECT ON THE ECONOMIC RESULTS.

For all practical purposes the combustible of coals may be considered to consist chiefly of carbon and hydrogen. When these two constituents burn completely with the oxygen of the air the products of the combustion are carbonic acid gas (CO_2) and water vapor (H_2O). The amount of oxygen supplied to obtain practically complete combustion must always be somewhat in excess of the amount

theoretically needed to convert all the carbon to CO_2 and all hydrogen of the combustible to H_2O. The most economical excess of oxygen depends on the nature of the coal, the method of feeding it into the furnace, the facilities for mixing oxygen with the combustible gases, and the extent of the combustion space. The oxygen supplied to the furnace is always accompanied by about four times its volume of nitrogen (N_2), which does not take any part in the combustion, but acts as a diluent. The gases leaving the furnace contain chiefly the following constituents: Carbonic acid gas (CO_2), water vapor (H_2O), free oxygen (O_2), and nitrogen (N_2).

If the combustion is not complete, as is generally the case, carbon monoxide (CO), free hydrogen (H_2), methane (CH_4), and other hydrocarbons may be found in the furnace gases in quantities varying with the incompleteness of combustion. Besides these compounds which are in the gaseous state, there may be combustible in the liquid or semiliquid state held in suspension as tiny tar globules. This latter form of combustible, on account of not being a gas, can not be determined by the volumetric method of analysis. Again, some of those compounds which exist as gases at the furnace temperature may condense when they are cooled in the gas-sampling apparatus; these, too, can not be determined volumetrically.

Usually the furnace gases are analyzed for CO_2, O_2, and CO. H_2O condenses almost entirely in the gas-sampling apparatus. The determination of H_2 and CH_4 is rather complex and requires considerable chemical skill and experience, and therefore it is seldom made. The combustible constituents are supposed to be in some proportion to the CO in the flue gas, and therefore CO is taken as an indication of incomplete combustion. Under ordinary conditions the percentage of CO and the other combustible gases is small; however, under bad conditions, or with the oxygen greatly reduced, the combustible constituents may amount to several per cent.

Within certain limits the percentage of CO_2 and O_2 in the furnace gases depends entirely upon the air supply; the larger the air supply the higher is the percentage of O_2 and the lower is the CO_2 content. This rule is true in so many cases that the percentage of CO_2 is taken as an indication of the air supply.

RELATION OF THE COMPOSITION OF FURNACE GASES TO THEIR TEMPERATURE.

The heat developed by the combustion of the fuel is mostly absorbed by the furnace gases whose temperature is thereby raised. Of course when a fire is started in a cold furnace part of the heat generated is radiated to the cold furnace walls and is absorbed by them, but after the walls have been heated up, the gases are the principal heat absorbers. The temperature to which the gases are

raised depends upon the quantity of heat evolved, and on the weight of the gases used or generated in the combustion. It is apparent, then, that with a given coal the temperature of the furnace gases depends on the air supply, that is, up to a certain limit beyond which the combustion of the coal becomes very incomplete and the temperature ceases to rise. The smaller the air supply the higher will be the temperature of the furnace gases. Since a high CO_2 content in the gases is, as a rule, the result of a small air supply, the higher the CO_2 percentage the higher the temperature; and also, the higher the O_2, the lower the temperature. This relation is shown in figure 27.

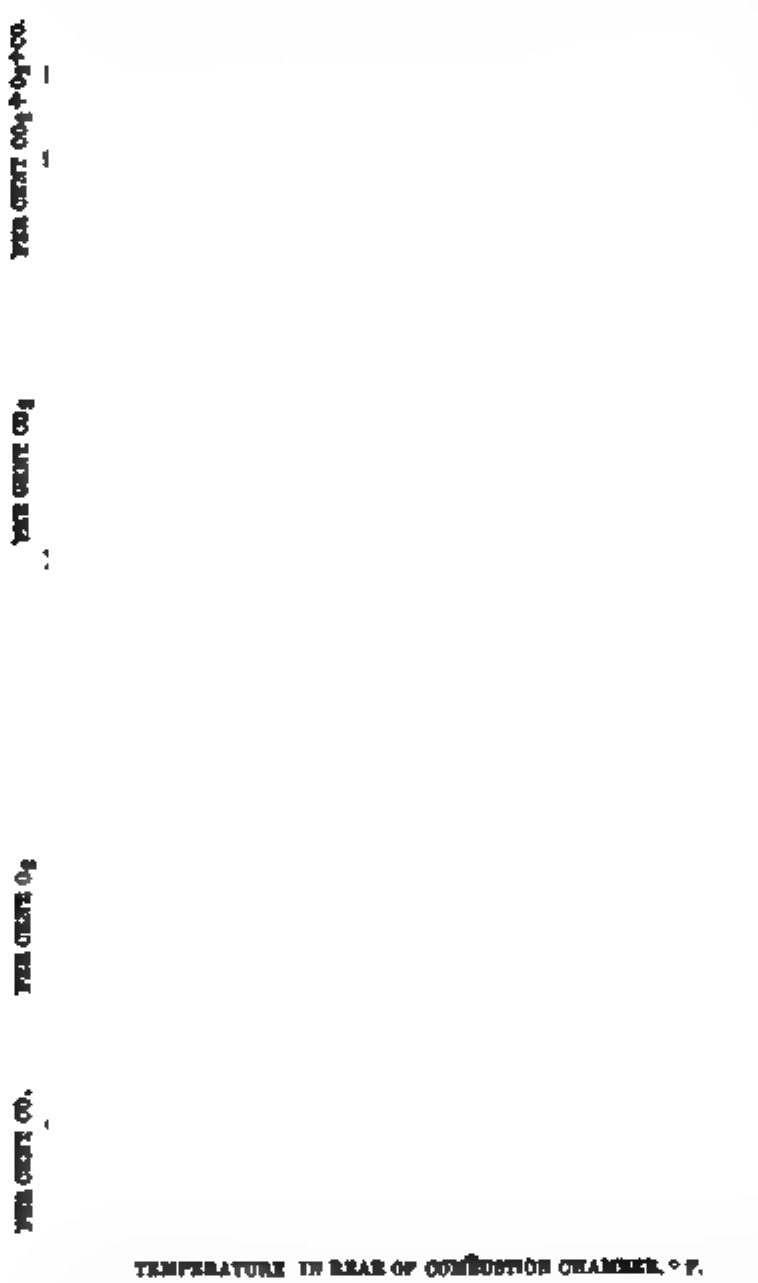


FIGURE 27.—Curves showing the relation between the percentages of CO, O_2, and CO_2 and combustion-chamber temperature. The gas samples and the temperatures were taken in the rear of the combustion chambers of boilers Nos. 1 and 2 during tests 318 to 362, inclusive.

The gas samples and the temperatures were both taken in the rear of the combustion chambers of boilers Nos. 1 and 2. The gas samples were collected with the water-jacketed sampler shown in figure 73, and the duration of collecting the sample was 30 minutes. The figures in the circles of the highest curve indicate how many samples were averaged to obtain each point. The temperature was taken with a Wanner optical pyrometer through a 2-inch opening in the side wall. It should be remembered that the optical pyrometer indicated lower temperatures than actually existed, because when short-flaming coals were burned, or when the boiler was run at lower capacities little flame was visible, and the instrument was pointed at the side wall, which was naturally cooler than the gases.

The lowest curve shows that as the free oxygen becomes less the percentage of CO increases, indicating that the combustion is less complete. The highest curve shows a gradual decrease in the Orsat totals when the air supply decreases. Perhaps part of this drop in

the Orsat totals is due to the presence of hydrogen and hydrocarbons, but it is a question whether all of the drop can be accounted for on this basis. The decrease toward the right is partly accounted for by condensation of some of the water formed by combustion, which shrinkage becomes larger and larger as the air supply is cut down toward the right.

EFFECT OF AIR SUPPLY AND THE COMPOSITION OF FLUE GASES ON THE EFFICIENCY OF THE STEAM-GENERATING APPARATUS.

It has been stated on page 195 that the part of the heat in the furnace gases which is below the temperature of the boiler is not available for absorption. Inasmuch as the temperature of any one boiler is nearly constant, the heat not available for absorption increases directly with the weight of gases. Therefore, by burning the fuel with a smaller air supply the quantity of heat unavailable for absorption is reduced, and the heat which is available is increased by the same amount. When a larger quantity of heat is made available for the boiler, the latter absorbs more of it and the over-all efficiency of the steam-generating apparatus is higher. If, however, the reduction of the air supply is carried too far the combustion may become so incomplete that a large part of the heat in the fuel is not developed, in which case the heat available for absorption may become smaller, although the heat not available is reduced. Thus for every furnace, every coal, and every method of feeding the fuel into the furnace, there is some minimum value beyond which it does not pay to reduce the air supply. There are, perhaps, very few boilers operated dangerously close to this limiting value; the majority of them are operated with too large an excess of air.

As previously stated, the most economical supply of air depends on the nature of the coal, the design of the furnace, the method of feeding the fuel, and perhaps on the rate of combustion. The most economic proportion of CO_2 in the furnace gases is from 10 to 15 per cent.

To show how the air-supply and the flue-gas composition affect economy in steam generation, several figures are presented. These figures were prepared from the results of the tests made at the fuel-testing plant at St. Louis and also from those made at the University of Illinois engineering experiment station. The grouping of the tests is on several bases.

EFFECT OF CARBON DIOXIDE IN FLUE GASES ON THE EFFICIENCY OF THE BOILER AND THE COMBUSTION SPACE.

Figure 28 shows the effect of the percentage of CO_2 on the combined efficiency of the boiler and the combustion space given in column 81 of Table 4 and designated as "boiler efficiency." The percentage of CO_2

is the amount determined by the Orsat analysis of the gases collected at the base of the stack. The amount of CO_2 in gases collected at this point is perhaps 2 or 3 per cent lower than it is in the rear of the combustion chamber, due to leakage of air into the boiler setting. (See p. 290). In the compilation of this chart all tests made on boilers Nos. 1 and 2 were used. The tests were grouped on the basis of the percentage of CO_2 in the flue gases. The efficiencies given in the chart are arithmetic averages for each group. The curve shows that the efficiency rises very rapidly as the per cent of CO_2 in the flue gases increases. This rise in efficiency, however, is probably not entirely due to a higher percentage of CO_2. Among the groups of tests at the extreme left, those made on low-grade coals predominate, so that the low efficiency may be partly due to the chemical nature of the coal. This is the principal objection against this figure.

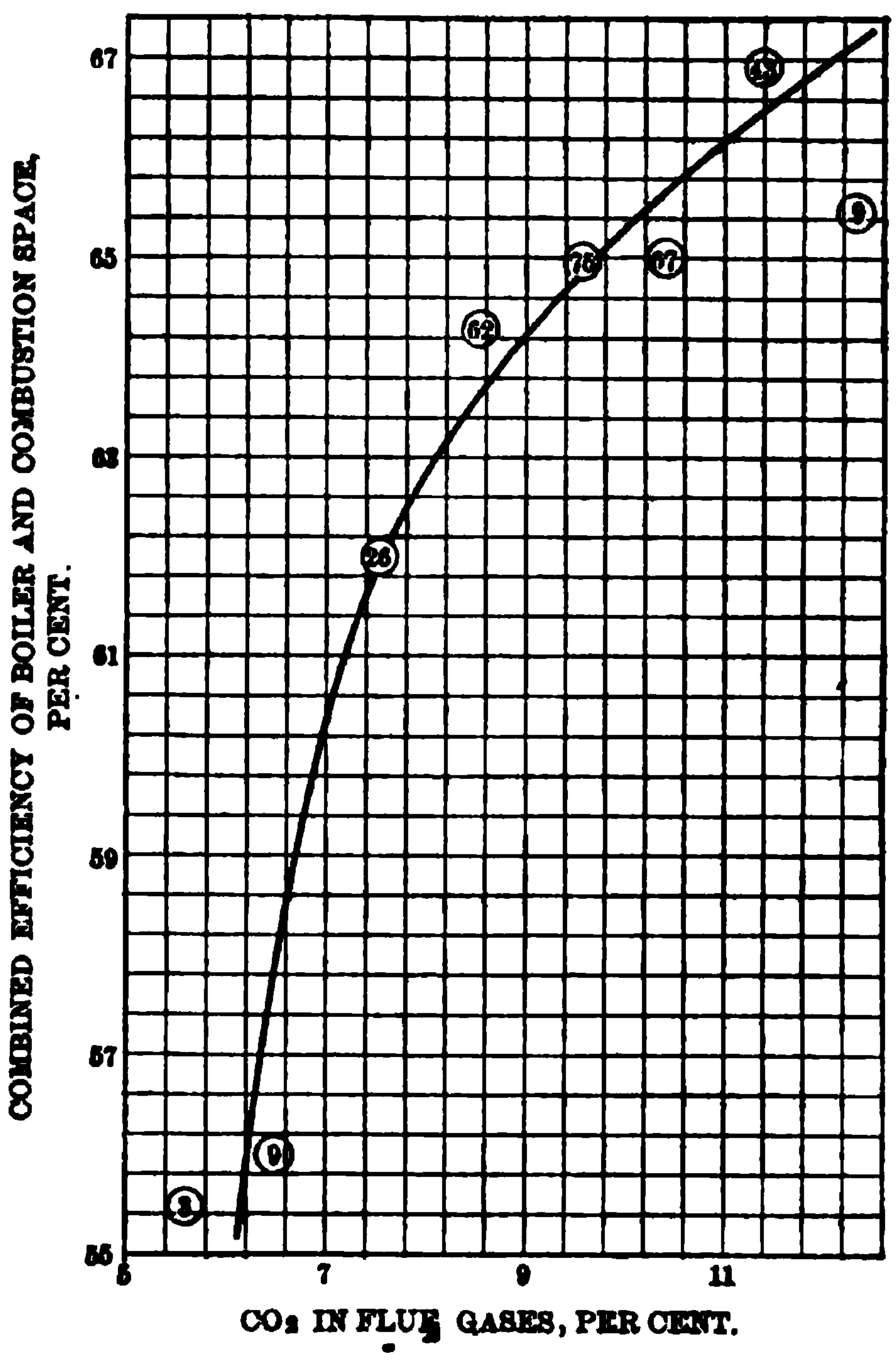


FIGURE 28.—Curve showing the effect of CO_2 in the flue gases on the combined efficiency of the boiler and the combustion space. Tests made on boilers Nos. 1 and 2.

EFFECT OF CARBON MONOXIDE IN FLUE GASES ON THE EFFICIENCY OF THE BOILER AND THE COMBUSTION SPACE.

Figure 29 has been compiled to show the effect of CO in the flue gases on the combined efficiency of the boiler and the combustion space. In its preparation the same tests were used as in figure 28. The grouping has been done on the basis of the percentage of CO in the flue gases. The points and the curve drawn through them show a very rapid drop in efficiency as the per cent of CO increases. The indication of this figure may seem inconsistent with figures 27 and 28. Figure 28 shows that the efficiency increases when CO_2 increases, and figure 27 shows that CO also increases with CO_2, so that apparently the efficiency should rise when CO increases. The explanation for this apparent inconsistency may be this: Although as a rule CO increases when the air supply is reduced—that is, when CO_2 increases, the reduction of the general air supply may not be always the cause of high CO. The deficient air supply may be only local, due to poor

conditions of the fuel bed—that is, a large quantity of air may pass through some parts of the fuel bed, while at other places the air supply may be very deficient, so that a large excess of air and incomplete combustion may occur at the same time. With coals forming large

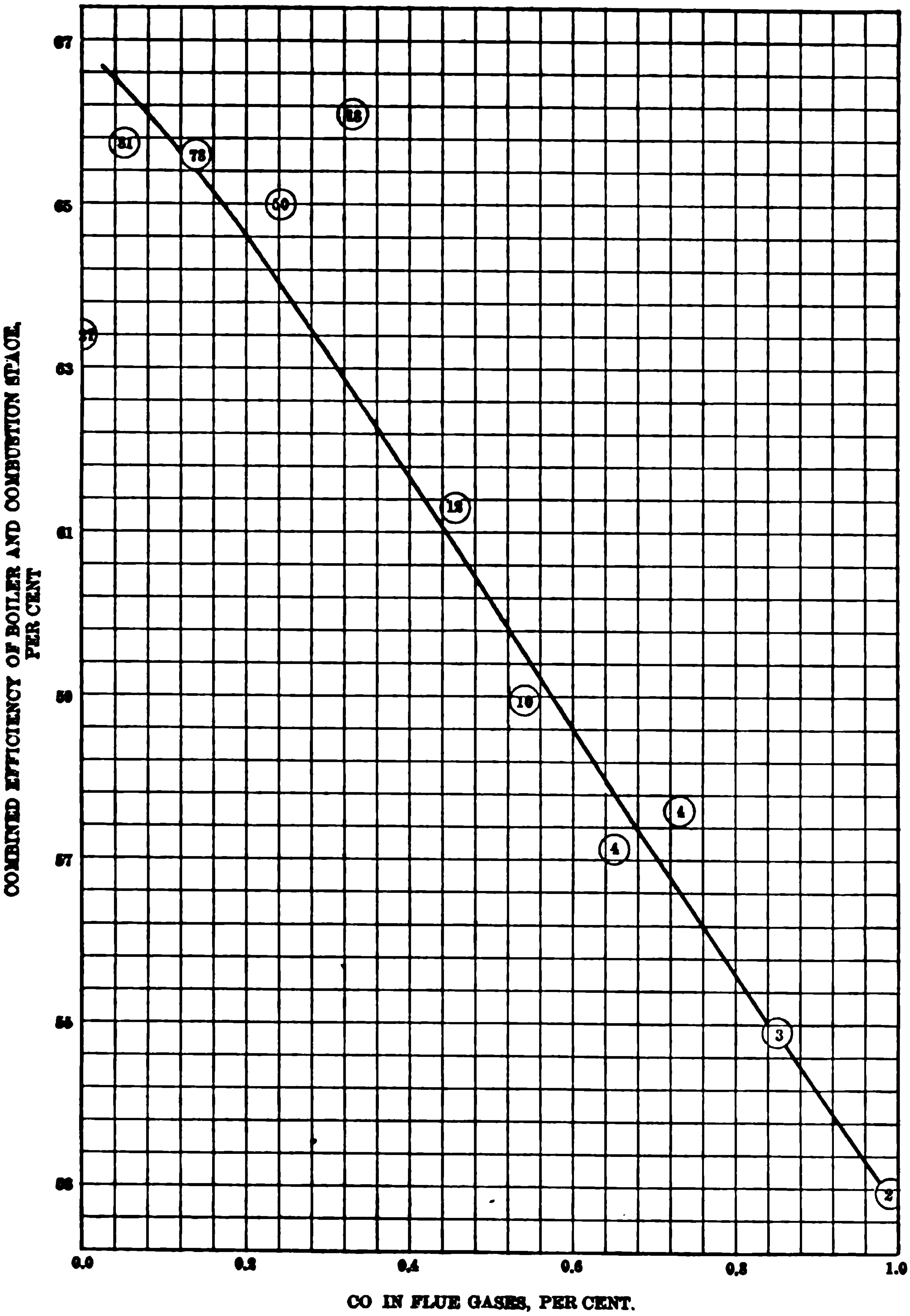


FIGURE 29.—Curve showing the effect of CO in the flue gases on the combined efficiency of the boiler and the combustion space. Tests made on boilers Nos. 1 and 2.

pieces of solid clinker on the grate such conditions are very probable. With such coals it is always a question whether more heat is lost by frequent cleaning of the fires or by bad conditions of the fuel bed on account of the formation of clinker.

Obviously, most of the tests at the right of figure 29 were made with coals that did not burn without clinkering.

The explanation just given is supported by the showing of figure 30. The latter has been prepared by grouping the tests made on boilers Nos. 1 and 2 on the basis of the combined efficiency of the boiler and combustion space, and averaging each of the percentages of CO and CO_2. The points at the left of the figure indicate a high excess of air and incomplete combustion at the same time.

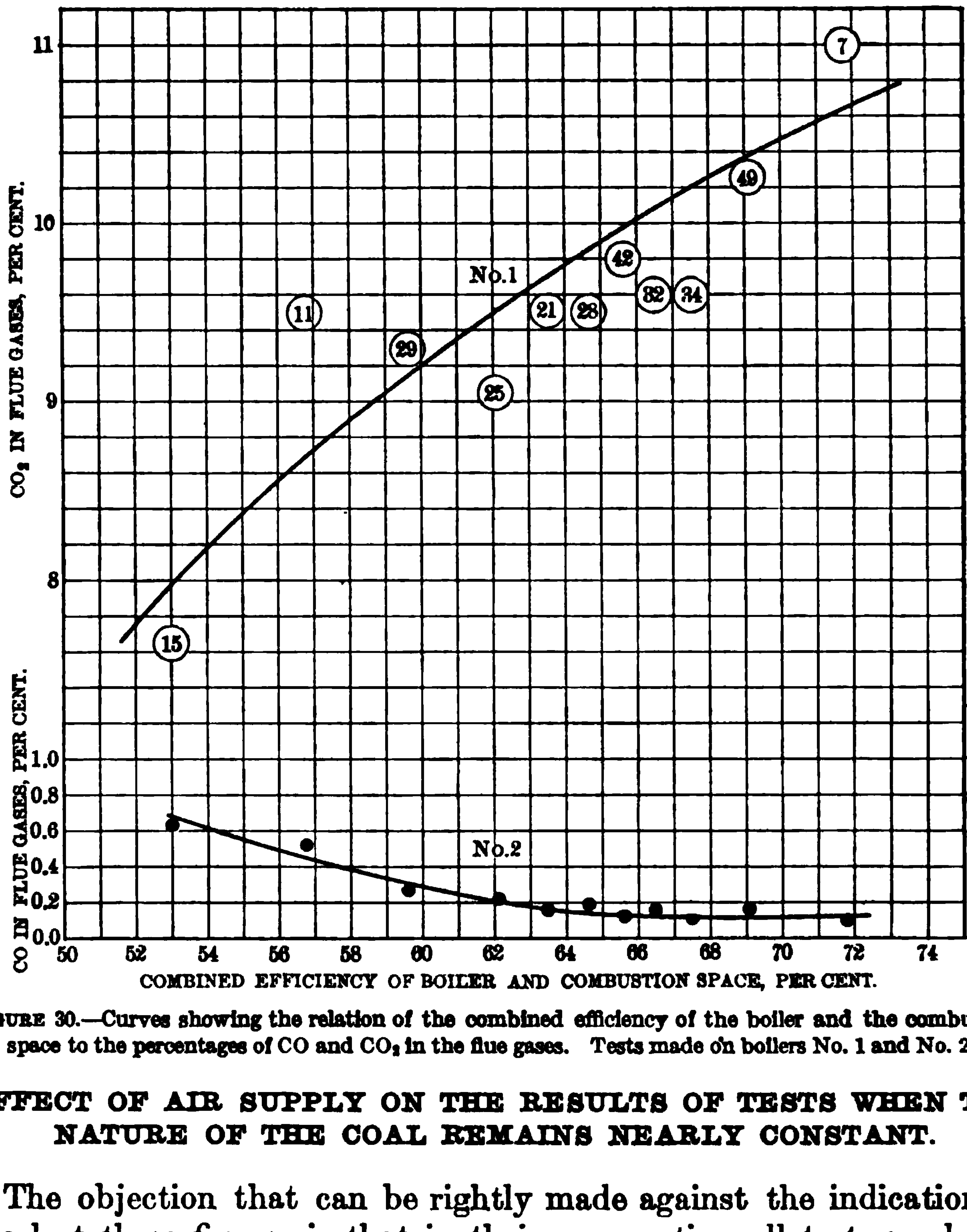


FIGURE 30.—Curves showing the relation of the combined efficiency of the boiler and the combustion space to the percentages of CO and CO_2 in the flue gases. Tests made on boilers No. 1 and No. 2.

EFFECT OF AIR SUPPLY ON THE RESULTS OF TESTS WHEN THE NATURE OF THE COAL REMAINS NEARLY CONSTANT.

The objection that can be rightly made against the indication of the last three figures is that in their preparation all tests made on boilers Nos. 1 and 2 were used, regardless of the nature of the coals. To eliminate this objection, figure 31 was prepared from tests made on Illinois coals only.

Inasmuch as all the combustible of the Illinois coals is nearly alike, the effect of the nature of the coal on the results of the tests is greatly reduced. Figure 31 was prepared in the same manner as the pre-

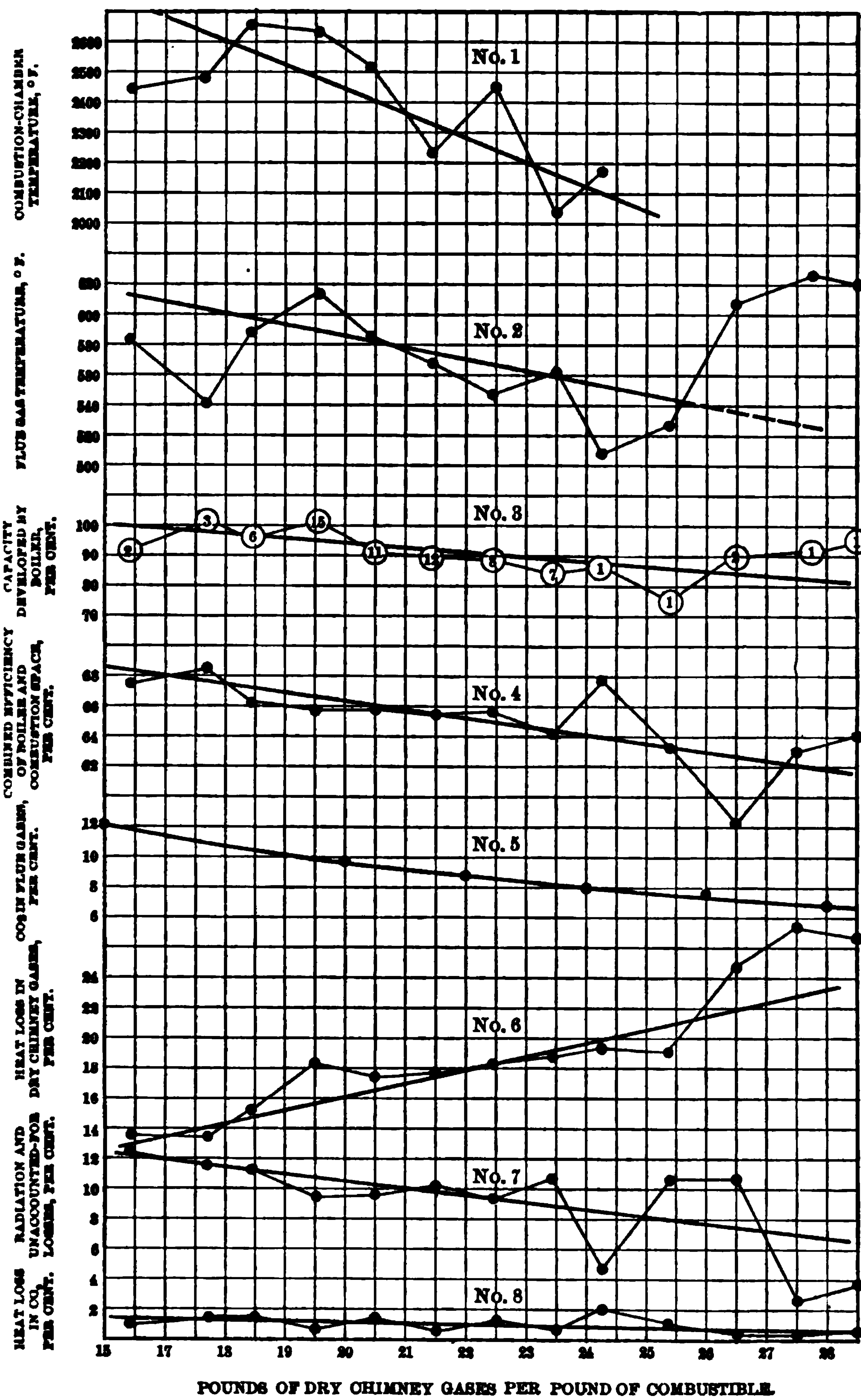


FIGURE 31.—Curves showing the effect of air supply on: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); capacity developed by boiler (No. 3); combined efficiency of boiler and combustion space (No. 4); CO_2 in flue gases (No. 5); heat loss in dry chimney gases (No. 6); radiation and unaccounted-for losses (No. 7); heat loss in CO (No. 8).

ceding figures. The grouping of the tests was done on the basis of the weight of the dry-chimney gases per pound of combustible. The most important curve in this chart is No. 4. It shows that with the increase of the weight of chimney gases from 16.5 to 27.5 pounds the combined efficiency drops from about 68 to about 62 per cent, or 6

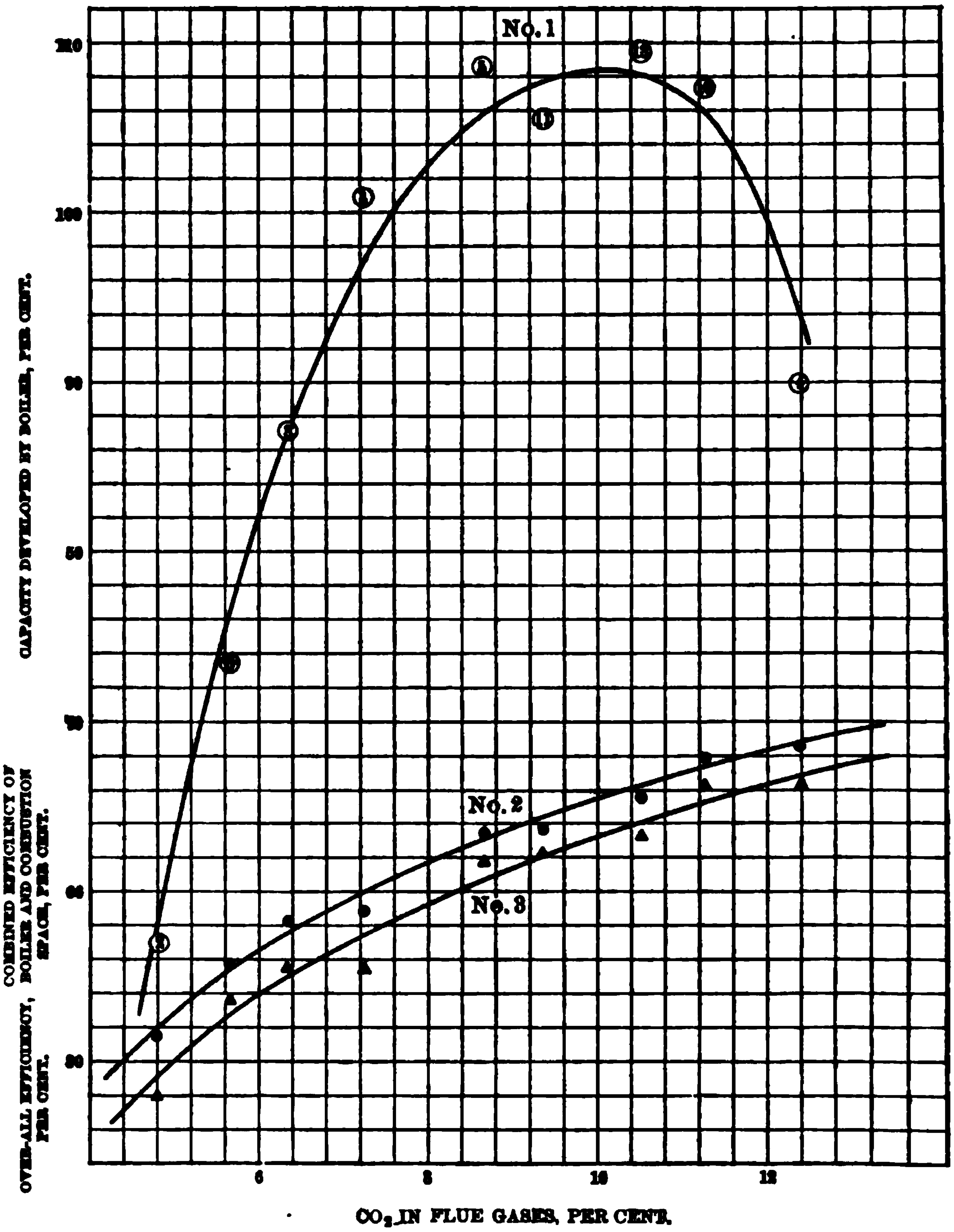


FIGURE 32.—Curve showing relation between the percentage of CO_2 in the flue gases and: Capacity developed by boiler (No. 1); combined efficiency of boiler and combustion space (No. 2); over-all efficiency of steam-generating apparatus (No. 3). Tests made with Illinois coals at the University of Illinois engineering experiment station on a Heine boiler like those at the fuel-testing plant, but equipped with a chain-grate stoker.

per cent; the capacity at the same time drops about 10 per cent. The drop in the efficiency is about the same as shown in figure 28 for the same drop in the percentage of CO_2 in the flue gases. The two figures can be compared by means of curve No. 5 of figure 31.

Curve No. 6 indicates a large increase in the heat loss in the dry-chimney gases as the air supply increases.

Curves Nos. 7 and 8 drop as the air supply increases, indicating more complete combustion.

To determine the effect of air supply on the efficiency when the furnace is equipped with a chain-grate stoker, figure 32 has been prepared from 64 tests made with Illinois coals at the University of Illinois engineering experiment station. The boiler on which the tests were made was exactly like those at the Government fuel-testing plant at St. Louis, but it was set up with a chain-grate mechanical stoker. The detailed description of the boiler and the tests is given in University of Illinois Bulletin No. 39. The efficiency platted in the figure is the American Society of Mechanical Engineers code items 72 and 73.

Curve No. 2 shows that when the CO_2 is increased from 7 to 12 per cent, which is about the range covered by figure 31, the efficiency of the boiler and combustion space rises from 59 to 68 per cent, or about 9 per cent, which is a little more than the rise shown in figure 31. Attention is called to the fact that the high efficiency points are about the same with both grates, but that the low points are about 3 per cent lower with the chain grate than with the hand-fired furnace. It should be borne in mind, however, that the coals burned on the chain grate with low CO_2 were small sizes, mostly below ½ inch, which fact may partly account for the low efficiencies.

Figure 33 is similar to figure 31. It has been prepared from tests made on boilers Nos. 1 and 2 with Indiana coals only.

Curve No. 4 shows that the variation of the efficiency with the air supply is very small. However, the range of the air supply covered is rather small. If the air supply were further increased the efficiency undoubtedly would drop faster than is shown by the curve. According to the indication of the curve, the efficiency is not much affected whatever the proportion of CO_2 may be, so long as it is between 8 and 12 per cent.

It will be noticed that curves Nos. 6 and 7 are nearly symmetrical with respect to the horizontal line of 14 per cent. This means that when the chimney loss is increased the unaccounted-for loss is decreased by the same amount, so that the sum of the two is about the same and the efficiency remains also about the same; that is, by decreasing the air supply the heat loss is shifted from the column of chimney losses to the unaccounted-for losses, the useful effect remaining the same.

Curves Nos. 7 and 8 indicate an increase of incomplete combustion when the air supply is reduced. The conclusion that can be drawn from figure 33 is that when the air supply is reduced from 25 to 16 pounds of gases per pound of combustible, what is gained in chimney-gas losses is nearly offset by incomplete combustion. This conclusion probably holds true only for Indiana coals when burned in a hand-fired furnace of the Heine type. The reader is cautioned

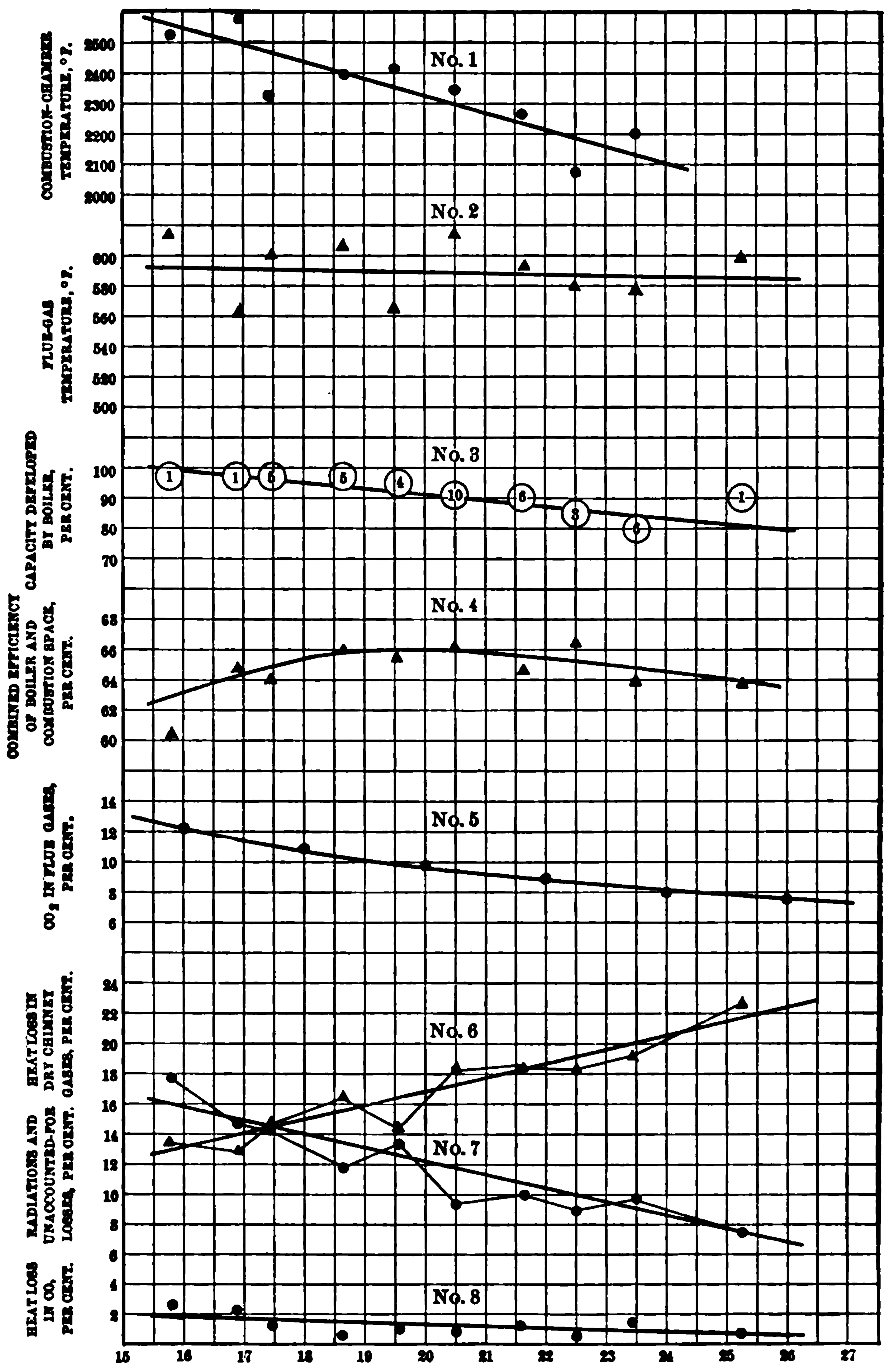


FIGURE 33.—Curves showing the effect of air supply on: Combustion-chamber temperature (No. 1) flue-gas temperature (No. 2); capacity developed by boiler (No. 3); combined efficiency of boiler and combustion space (No. 4); CO_2 in flue gases (No. 5); heat loss in dry chimney gases (No. 6); radiation and unaccounted-for losses (No. 7); heat loss in CO (No. 8). Tests made on Indiana coals only.

against applying it to other cases without giving due consideration to all conditions differing from those that existed at the fuel-testing plant.

In general it may be safely stated that high percentages of CO_2 in flue gases is one of the principal requisites of high efficiency of the steam-generating apparatus. However, it should be kept in mind that high CO_2 does not mean the same figure for all furnaces; that is to say, the most economical CO_2 percentage will be different for different coals and different furnaces.

EFFECT OF COMBUSTION-CHAMBER TEMPERATURE ON RESULTS OF TESTS.

High temperature in the rear of the combustion chamber is mainly the result of a low supply of air. It may be also the result of the rate of combustion or the nature of the coal. It depends entirely on the cause of the high temperature whether the efficiency is thereby raised or lowered. If the high temperature is caused by a reduced air supply, the efficiency of the steam generator will generally increase; if it is caused by a high rate of combustion or the nature of the coal, the efficiency is likely to drop; or, if it is the result of all three causes combined, the effects may be neutralized and the efficiency may remain constant.

It has been shown in figure 27 that the reduction of air is, within reasonable limits, accompanied by a rise in combustion-chamber temperature. This relation is obvious and is generally admitted. It has been also shown in figures 28, 30, 31, and 32 that the efficiency rises when the air supply is reduced, at least within the range that has been investigated. It is therefore reasonable to expect that a high combustion-chamber temperature is accompanied by higher efficiency of the steam-generating apparatus.

In figures 18, 21, 24, and 26 it has been shown that the combustion-chamber temperature rises when the rate of combustion increases. The same grouping of the same tests in figures 17, 20, 23, and 25 show that the efficiency drops as the rate of combustion increases. By inference it can be said that according to these figures the efficiency drops when the combustion-chamber temperature rises. It has been explained on page 203 that as the rate of burning coal increases the point of the most intense combustion of the volatile combustible recedes to the rear of the combustion chamber. Thus the distance between this point of most intense combustion and the point of temperature measurement is shortened, and consequently less heat is dissipated from the gases as they pass between the two points. The result is that the temperature in the rear of the combustion chamber is higher with higher rates of combustion, although the air supply may remain the same.

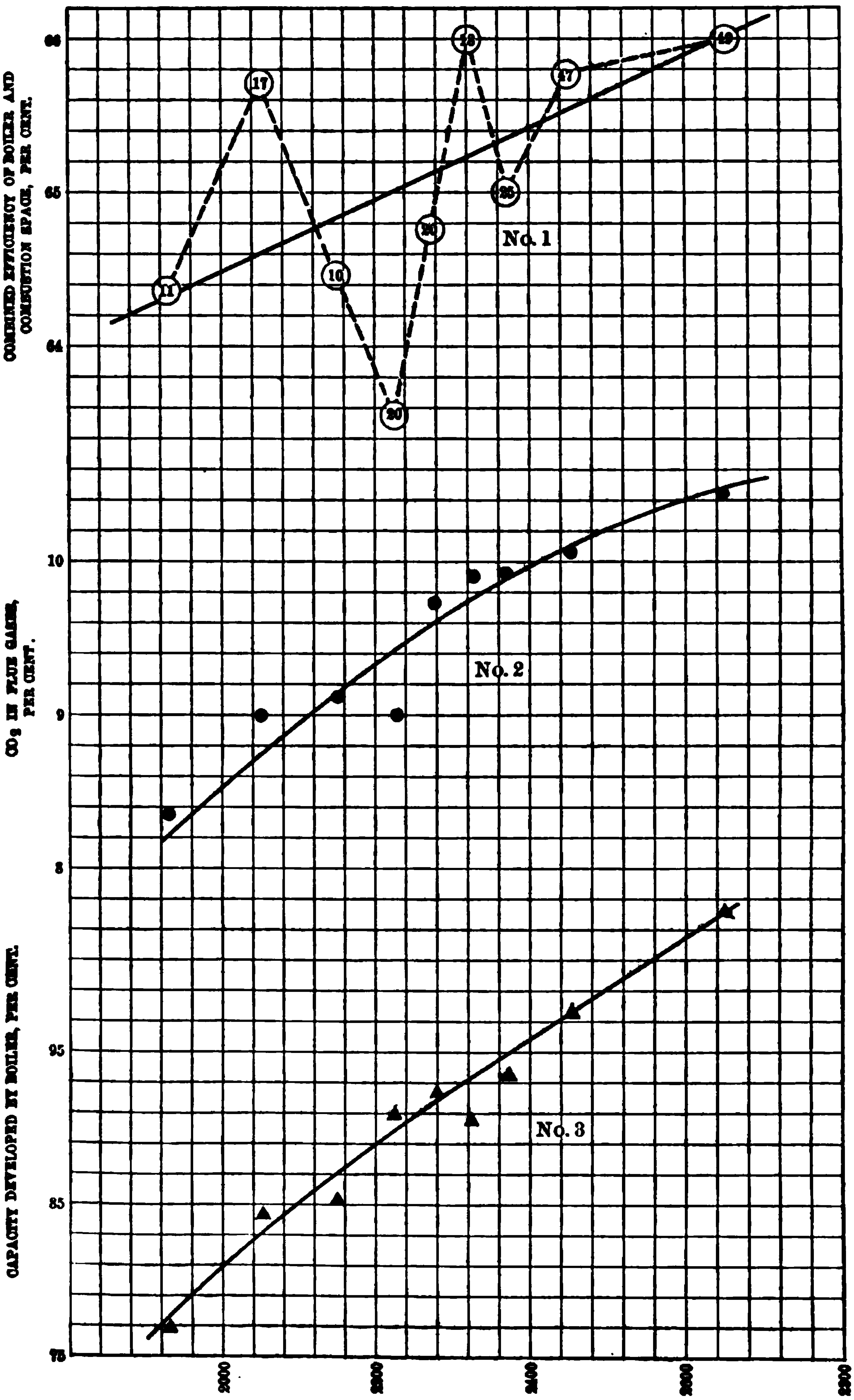


FIGURE 34.—Curves showing the relation of the temperature in the rear of the combustion chamber to: Combined efficiency of boiler and combustion space (No. 1); CO_2 in flue gases (No. 2); capacity developed by boiler (No. 3). Tests made on boilers Nos. 1 and 2.

In a boiler furnace the volatile combustible of coal has to be burned in the space between the grate and the entrance of the gases among the tubes of the boiler. If the quantity of the volatile matter is small and burns easily, the point of the most intense combustion will be close to the grate. On the other hand, if the quantity of the volatile combustible is large and burns with difficulty, the point of the most intense combustion will be far from the grate. Although the rate of burning the coal and the rate of air supply may be the same in the two cases, it is apparent that the coal with the high volatile combustible will show a higher temperature in the rear of the combustion chamber than coal low in volatile combustible.

Since with high rates of burning coal and with coals high in volatile matter the point of the most intense combustion of the gases is near the end of the furnace space, the gases enter among the boiler tubes less completely burned than when the rate of combustion is low, or when the coal is low in volatile matter. We have therefore a loss due to incomplete combustion accompanying high furnace temperatures. Also, since the gases enter the boiler-tube space at higher temperature they leave the heating surfaces of the boiler at higher temperature, and consequently more heat is wasted through the stack. There is then a loss due to less complete absorption of heat accompanying high temperatures in the rear of the furnace. We can see that high temperature in the rear of the combustion chamber is not a positive assurance of high efficiency.

Figure 34 was prepared from all the tests made on boilers Nos. 1 and 2 in which the combustion-chamber temperatures were measured, regardless of the nature of the coal or the rate of combustion. The grouping of the tests was done on the basis of the combustion-chamber temperature. The figures in the small circles of curve No. 1 indicate the number of tests averaged to obtain each of the points. The object of preparing this figure was to show whether, in general, high furnace temperatures are conducive to high efficiency.

Curve No. 2 shows that one of the causes of the rise in the combustion-chamber temperature was the reduction in air supply. The rapidly increasing capacity shown by curve No. 3 is undoubtedly due to the increasing rate of combustion. One can say then that the rise in the combustion-chamber temperature is due, at least, to two causes, namely, the reduction of air supply and the increased rate of combustion. Since all tests made on the two boilers were used in the preparation of the curve, coals high in volatile matter perhaps predominate at the right of the curve and are, therefore, also the cause of the rise in the combustion-chamber temperature. There are then, very likely, all the three causes previously discussed coming into effect, and therefore little or no rise in efficiency is to be expected when the combustion-chamber temperature rises.

Curve No. 1 shows that the average increase in the combined efficiencies of boiler and combustion space is only about 2 per cent for a rise in combustion-chamber temperature from 1,900° to 2,700° F. However, considering the increase of about 30 per cent in the capacity of the boiler, one must conclude that high furnace temperatures are

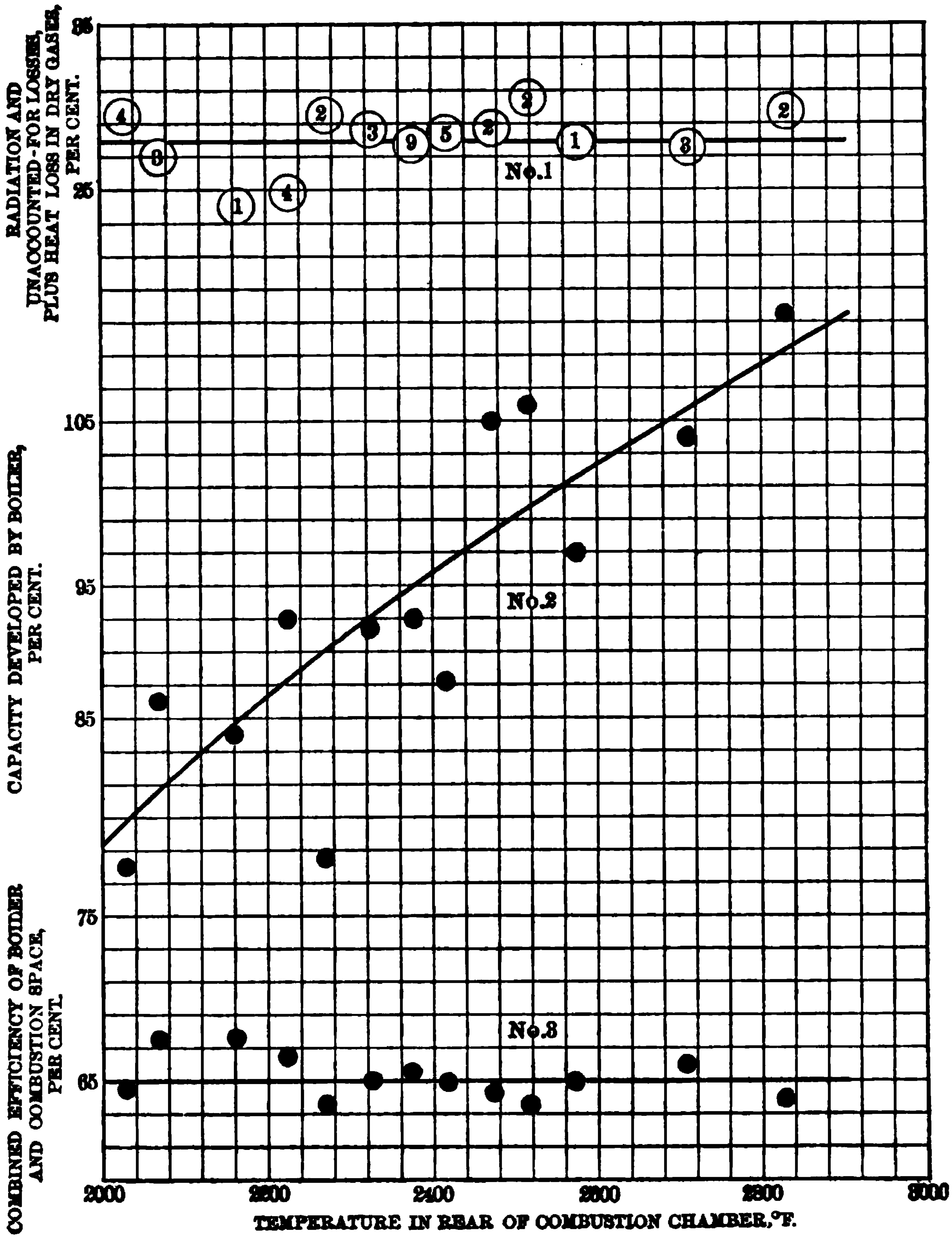


FIGURE 35.—Curves showing the relation of the temperature in the rear of the combustion chamber to: Radiation and unaccounted-for losses, plus heat loss in dry gases (No. 1); capacity developed by boiler (No. 2); combined efficiency of boiler and combustion space (No. 3).

desirable so far as commercial performance of the apparatus is concerned.

Figure 35 has been prepared in the same way as figure 34, with the exception that only tests made on Illinois coals were used in its preparation. Tests on other coals were left out to eliminate the

effect of the nature of the coal on the combustion-chamber temperature and on the results of the tests.

Curve No. 2 indicates that an increasing rate of combustion was to a considerable extent the cause of the rise in the combustion-chamber

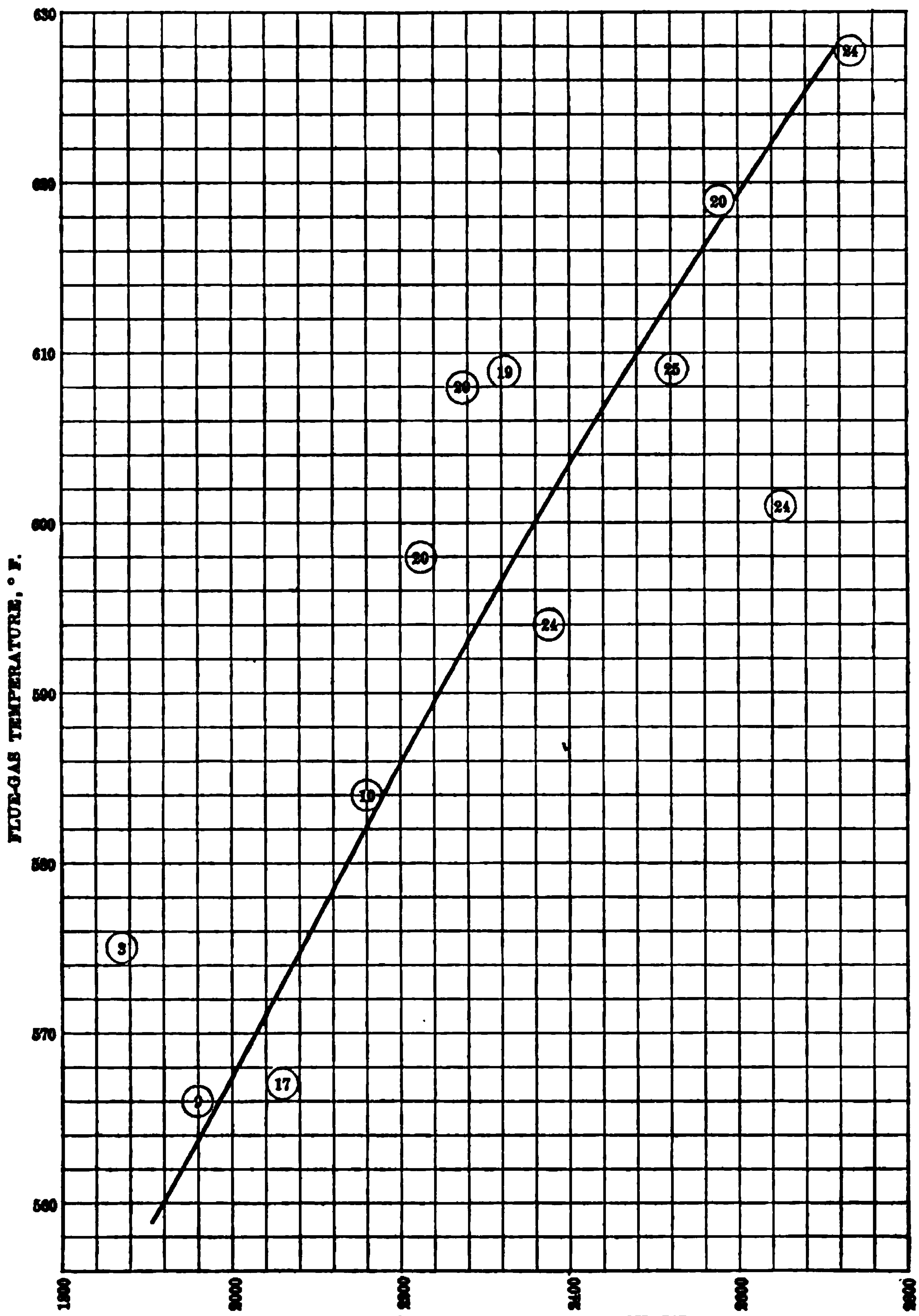


FIGURE 36.—Curve showing the relation between combustion-chamber temperature and flue-gas temperature. Tests made on boilers Nos. 1 and 2.

temperature. For this reason one should not expect an appreciable increase in the efficiency when the combustion-chamber temperature rises.

Curve No. 3 shows that, in general, the combined efficiency of the boiler and combustion space remains nearly constant throughout the whole range of the combustion-chamber temperature. If the rise in the temperature were caused by the reduction in air supply alone the combined efficiency would rise; or, if it were caused by increased rate of combustion alone the efficiency would drop. Since both of these causes are active their effects are neutralized and the efficiency remains constant.

Curve No. 1 shows that the sum of the heat loss in the dry chimney gases plus the radiation and other unaccounted-for losses remains nearly constant, no matter what the combustion-chamber temperature may be. Curves Nos. 1 and 3 show a peculiar relation to each other in that their respective points are symmetrically located with respect to a horizontal line running through the middle of the figure. This means that whenever the efficiency is low the heat loss is in one of the two items of curve No. 1.

Considering the large increase in the boiler capacity with no loss in the efficiency, figure 35 shows that high temperatures are favorable to economic operation of steam boilers.

There is one objectionable feature connected with high furnace temperature which may affect the efficiency of a boiler plant even though the boiler efficiency may be higher. This feature is the comparatively short life of the fire-brick lining of the furnace and proportionately larger repair expenses. Considering the durability of the furnace lining it would seem advisable not to run the furnace at excessively high temperatures. The latter can be lowered not by using more air, but by changing the construction of the furnace in such a way that part of the heat is absorbed by the boiler while the process of combustion is going on. Of course this heat absorption should not be carried so far as to reduce the temperature of the gases below the ignition point, in which case smoke would result.

RELATION BETWEEN THE COMBUSTION-CHAMBER TEMPERATURE AND FLUE-GAS TEMPERATURE.

In the preceding discussions the statement has been made several times that the flue-gas temperature rises with the temperature in the rear of the combustion chamber. To show that, in general, this statement is true figure 36 has been prepared from all the tests made on boilers Nos. 1 and 2. The figure shows that the relation between the two temperatures is as stated. We may say then that, in general, the hotter the gases are when entering the boiler the hotter they are when they leave the boiler. Similarly, the cooler they are when they enter the boiler the lower is the flue-gas temperature. There are scarcely any arguments needed to prove that if low flue-gas temperatures are to be accompanied by high efficiency, the combustion-chamber temperature should be made low by having the boiler absorb part of the heat from the gases and fuel bed during the process

of combustion. Of course, such reduction in the combustion-chamber temperature can be attained only by changing the furnace. For example, in the Heine furnace the combustion-chamber temperature can be reduced by forming the lower baffle with flat tiles, which are merely laid on top of the lowest row of water tubes instead of having the latter entirely inclosed with tiles. This change may increase the efficiency of the outfit 3 to 4 per cent, although at higher rates of combustion it may increase the incomplete combustion and the tendency of the furnace to smoke.

For a description and the results of a series of comparative tests made on a Heine boiler with the lower baffle similarly modified, the reader is referred to Bulletin No. 34 of the University of Illinois. The tests were made at the Universtiy of Illinois engineering experiment station in a boiler mentioned in connection with figure 32. The series consisted of eight tests; four of them were made with the lowest row of tubes entirely inclosed with C-shaped tiles, and four were made with the lower baffle formed with T-shaped tiles, which were merely laid on top of the tubes, leaving the latter exposed to radiation from the fuel bed and the flames. Table 5 gives the principal results of these tests.

TABLE 5.—*Results of comparative tests made with two types of tile-roof furnaces at the University of Illinois experiment station.*

Items.	Tests with C-shaped tiles.					Tests with T-shaped tiles.				
	1	2	3	4	Average.	1	2	3	4	Average.
Capacity (per cent)	102.0	102.0	105.0	102.0	102.8	106.0	104.0	102.0	105.0	104.0
Efficiency (per cent)	66.3	64.4	65.9	65.8	65.6	68.6	69.4	67.4	68.8	68.5
Temperature above fuel bed (° F.)	2,052.0	2,086.0	2,073.0	2,053.0	2,066.0	1,893.0	1,870.0	1,869.0	1,902.0	1,883.0
Temperature in rear combustion chamber (° F.)	1,677.0	1,534.0	1,721.0	1,636.0	1,642.0	1,409.0	1,418.0	1,325.0	1,384.0	1,384.0
Flue-gas temperature (° F.)	549.0	565.0	563.0	556.0	558.0	496.0	484.0	458.0	432.0	467.0
Per cent CO_2 in flue gas	7.5	5.1	7.7	7.0	6.8	6.7	7.7	7.7	7.9	7.5

RELATION OF COMPOSITION OF COAL TO RESULTS OF STEAMING TESTS.

In the preceding paragraphs were considered the effects on the results of the steaming tests of such conditions as can be to some extent controlled by the man in charge of the fire. By properly adjusting these conditions the efficiency of the steam-generating apparatus can be improved. In the present chapter will be discussed the effects of the chemical composition of the coal on the results of the tests. The composition of the coal can not be changed and therefore its effect on the results is of more permanent nature. Nevertheless, if the furnace were so modified as to be better adapted for certain classes of coal the results could be improved. The composition of coal generally affects the result through one, two, or several of the conditions previously discussed.

The two chief losses in the process of steam generation are the heat loss in the dry chimney gases, and the heat loss through incomplete combustion. The chimney loss may be made unreasonably high by the use of a large excess of air. Incomplete combustion is directly caused by an insufficient air supply which may be either local or general. Either of these extremes may be caused by the composition of the coal. The coal may be very fusible, in which case the surface of the fuel bed forms one solid layer of semiliquid fuel which effectively stops the passage of air through the grate, and at the same time a large excess of air may be fed into the furnace through the firing door. The same local excess or insufficient air supply may be caused by the fusion of the ash on the grate. Again, the volatile matter of some coals may be driven off so rapidly after a fresh charge that the average air supply is far too small to burn it, whereas one or two minutes after firing the same air supply may be greatly in excess. Thus the chemical nature of the coal is responsible for large or small supply of air, and therefore indirectly for large chimney losses or losses of incomplete combustion.

In order to study the effects of the nature of coal on the economy in the process of steam generation, the tests made on boilers Nos. 1 and 2 were grouped on the bases of various chemical constituents of the coals, and figures 37 to 52 were prepared. As on all previous charts, the factors which were used for the bases of the groupings of the tests are given as abscissas, and the items of the results of the tests on which the effects of these factors are desired to be shown are given as ordinates. The ordinate of each point on these charts is the arithmetic average of all the tests of each group, so that the indication obtained by each curve shows only the general tendency. This fact should be kept in mind when drawing conclusions from these charts. The number of tests forming each group is given by the figure inside of each small circle representing the points.

EFFECT OF THE VOLATILE MATTER OF COAL ON THE EFFICIENCY.

The volatile combustible is one of the troublesome constituents of coal, particularly if the latter is burned in a hand-fired furnace. Firing by hand is an intermittent process. The charging itself takes one-half to one minute and supplies the furnace with fuel for four or five minutes. Careless firemen make the charges a great deal heavier. Most of the volatile matter is driven off the coal during the first two minutes after charging, and most of it is burned while in the combustion space of the furnace. Generally during these two minutes not enough air is admitted, and the time during which the volatile matter and the air stay within the combustion space is too short for the two to be thoroughly mixed and the combustible consumed. There is, therefore, during these first two minutes incomplete combustion, of

which black smoke is a visible evidence. After the volatile matter has been driven off the fixed carbon burns on the grate and stays there until thoroughly consumed or gasified. The air during this period of the firing cycle may be about right for economic combustion, but generally it is high. It is obvious from the intermittent feeding of coal in hand firing that unless the air supply is constantly varied during each firing cycle there is apt to be alternately shortage and

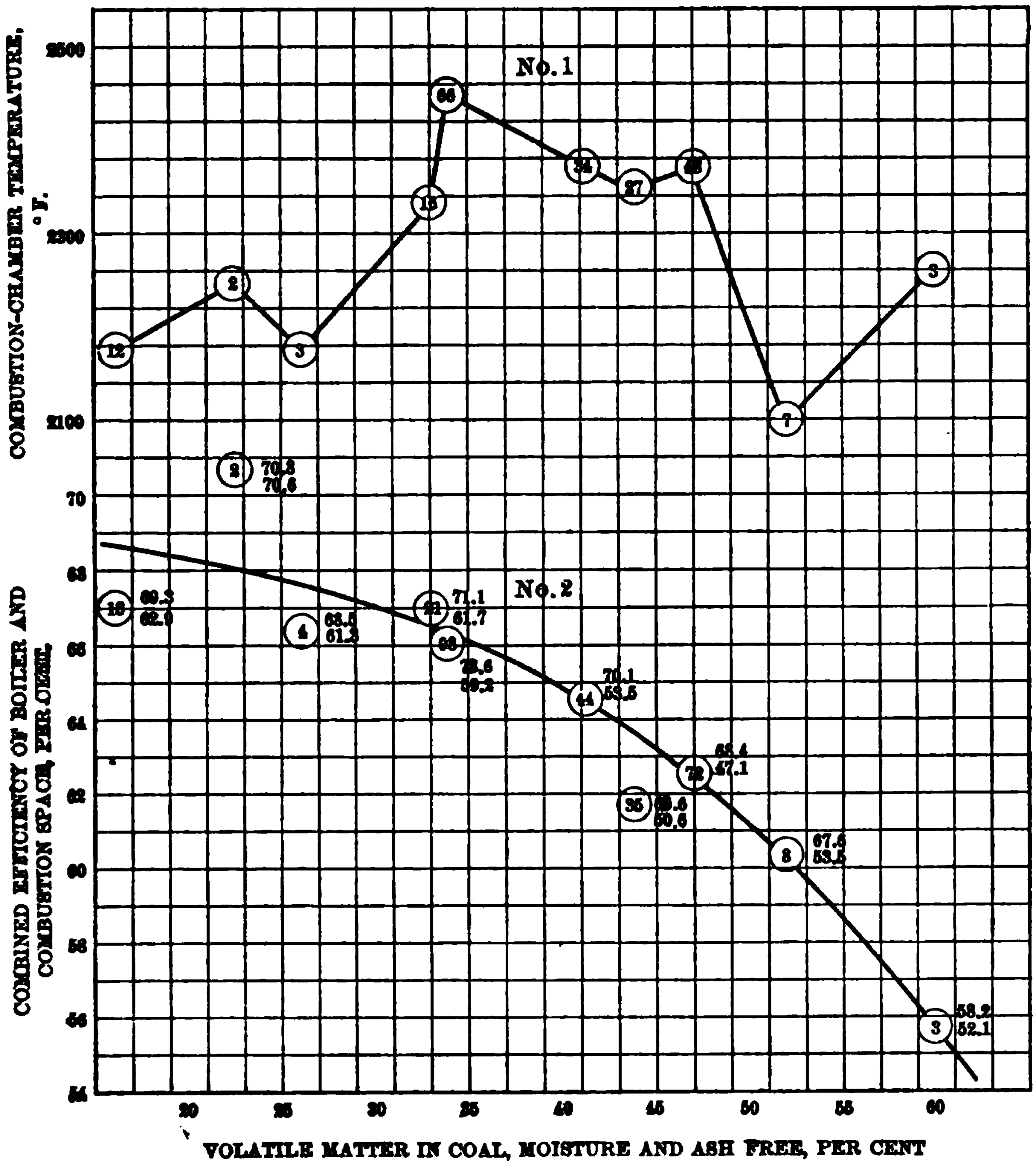


FIGURE 37.—Curves showing the effect of the volatile matter in moisture and ash-free coal on: Combustion-chamber temperature (No. 1); combined efficiency of boiler and combustion space (No. 2). Tests made on boilers Nos. 1 and 2.

excess of air, with the consequent heat losses. It must not be understood that all the volatile combustible is driven off during the first two minutes after firing, and that all the remaining fixed carbon burns completely during the remaining two or three minutes before the next charge is fired. There is some volatile combustible leaving the fuel bed during the fourth or even fifth minute, but the quantity is so small and is of such nature that the air supply is more than

sufficient to burn it before it leaves the combustion space. The fixed carbon may stay on the grate one hour or even longer before it is completely consumed.

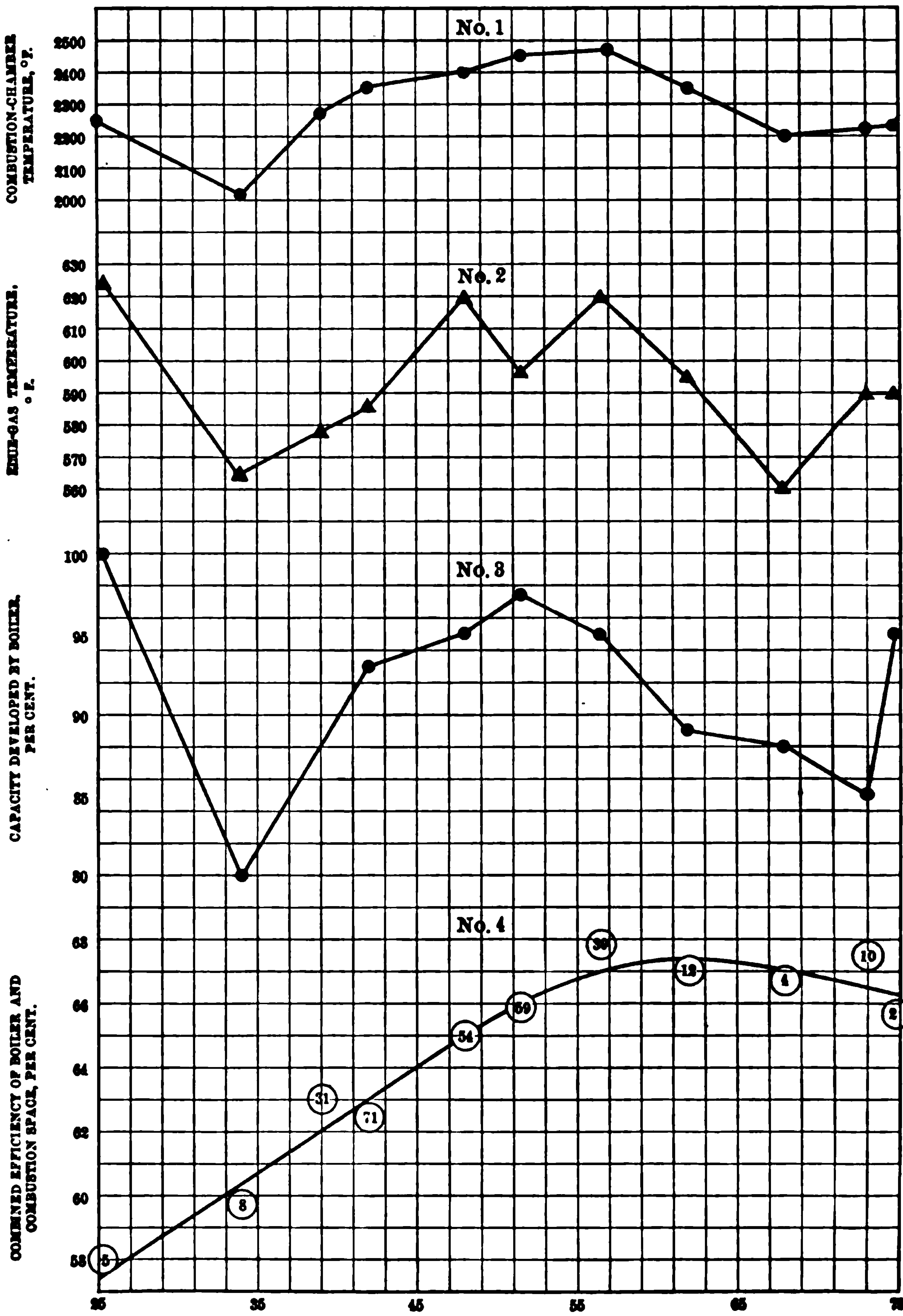


FIGURE 38.—Curves showing the relation between the percentage of fixed carbon in coal and: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); capacity developed by boiler (No. 3); combined efficiency of boiler and combustion space (No. 4).

The large quantity of the volatile combustible distilled from the fuel bed during the first two minutes after firing is not entirely respon-

sible for the incomplete combustion losses. The loss is to a considerable extent also due to chemical composition and physical state. Only part of the volatile combustible leaves the fuel bed as light, readily combustible gases; the remainder passes through the space of the furnace as heavy gases, tarry vapors, and other carbon-hydrogen compounds in semiliquid or solid states. The last two forms of combustible, owing to their physical state, are particularly difficult to burn completely in the short time they stay within the combustion space of the furnace. They are generally responsible for a great deal of the smoke made in the hand-fired furnace.

Owing to the above-discussed difficulties in burning volatile combustible, coals containing high percentages of volatile matter generally do not give as good results in steam-generating apparatus as high fixed-carbon coals. This fact is plainly shown in figures 37 and 38. The lower curve of figure 37 shows that, in general, the combined efficiency of the boiler and the combustion space drops from 68 to about 56 per cent when the volatile matte increases from 20 to 60 per cent. The two numbers beside each circle indicate the highest and the lowest efficiency obtained within each group of the tests. It will be noticed that the highest efficiencies are approximately the same for all groups, excepting the one of the highest volatile matter. The lowest efficiency values of each group, on the other hand, fall off very rapidly as the volatile matter increases. This fact may be explained in this way: There is no particular difficulty in burning the low volatile matter coals, consequently good efficiency is obtained in all the tests; but as the volatile matter becomes higher the difficulty in burning the coal increases and most of the tests come out with low efficiency, though a few tests may show good results. The conclusion is that, with the same economy, a great deal more care and skill are required to burn high volatile coals under steam boilers than are required to burn low volatile coals.

The upper curve of figure 37 shows that the highest temperatures in the rear of the combustion chamber were obtained with coals running 30 to 50 per cent in volatile matter. The coals lower in volatile matter have their points of intense combustion near the grate, so that part of the heat is absorbed by the boiler through the tile roof before the gases reach the rear of the combustion chamber. The coals high in volatile matter are mostly low-grade fuels with high ash and high moisture, which two constituents tend to lower the furnace temperature.

Curve No. 4 of figure 38 confirms the indication of the lower curve of figure 37.

Curves Nos. 1 and 2 of figure 38 rise and fall together, showing that high furnace temperatures are accompanied by high flue-gas temperatures, which relation is, of course, natural. The combustion-

chamber temperature does not seem to bear any relation to the percentage of fixed carbon in coal. The same is true of the capacity developed by the boiler as shown by curve No. 3.

EFFECT OF PERCENTAGE OF ASH ON RESULTS OF TESTS.

Ash in coal is impurity and is objectionable for several reasons. In this discussion ash is considered only as a hindrance to the proper combustion of the coal.

The ash, even if not fusible, increases the resistance of the fuel bed to the flow of air, thus reducing the rate of combustion. If the rate of combustion is to remain the same, higher "drafts" must be carried when burning high-ash coals. Higher "drafts" (lower pressures inside the boiler setting) will necessarily increase the leakage of air into the boiler setting so that the flue-gas analysis may show a high excess of air.

If the ash is uniformly distributed through the coal and particularly if it is tough, it may form an insulating layer around the burning pieces of coal so that the oxygen passing through the fuel bed can not readily come in contact with the combustible. Consequently, a large quantity of the oxygen may pass through the fuel bed uncombined. Thus, the air supply may become too high for good economy.

If the ash is fusible clinkers are formed which may entirely shut off the flow of air through some parts of the fuel bed while a few places remain open, and through them a large excess of air may rush into the furnace. Thus incomplete combustion and a large supply of air may both cause heat losses at the same time.

A further loss directly attributable to ash is the unavoidable removal from the furnace of some of the combustible matter along with the ash when cleaning fires. As the ash and clinkers, as well as the combustible, are pulled out of the furnace at a red heat a small quantity of heat is wasted in this manner.

Besides the tendency to cause the above heat losses, ash in coal is apt to reduce the capacity of the boiler. It has been stated that the presence of ash in the fuel bed increases the resistance to the flow of air through the bed and thereby reduces the rate of combustion. Since the capacity is a direct function of the rate of combustion, high ash causes low capacity. The ash affects the capacity in another way; while the ash and clinkers are being removed from the furnace the operation of the latter is almost entirely suspended during 10 to 20 minutes, a fact that greatly reduces the steam production over extended periods.

Thus high ash in the coal may reduce the efficiency of the steam-generating apparatus by causing too large a supply of air with a possible incomplete combustion due to local deficiency of air supply.

High ash reduces the capacity of a steam boiler by reducing the rate of combustion, and also by the fact that during the time of

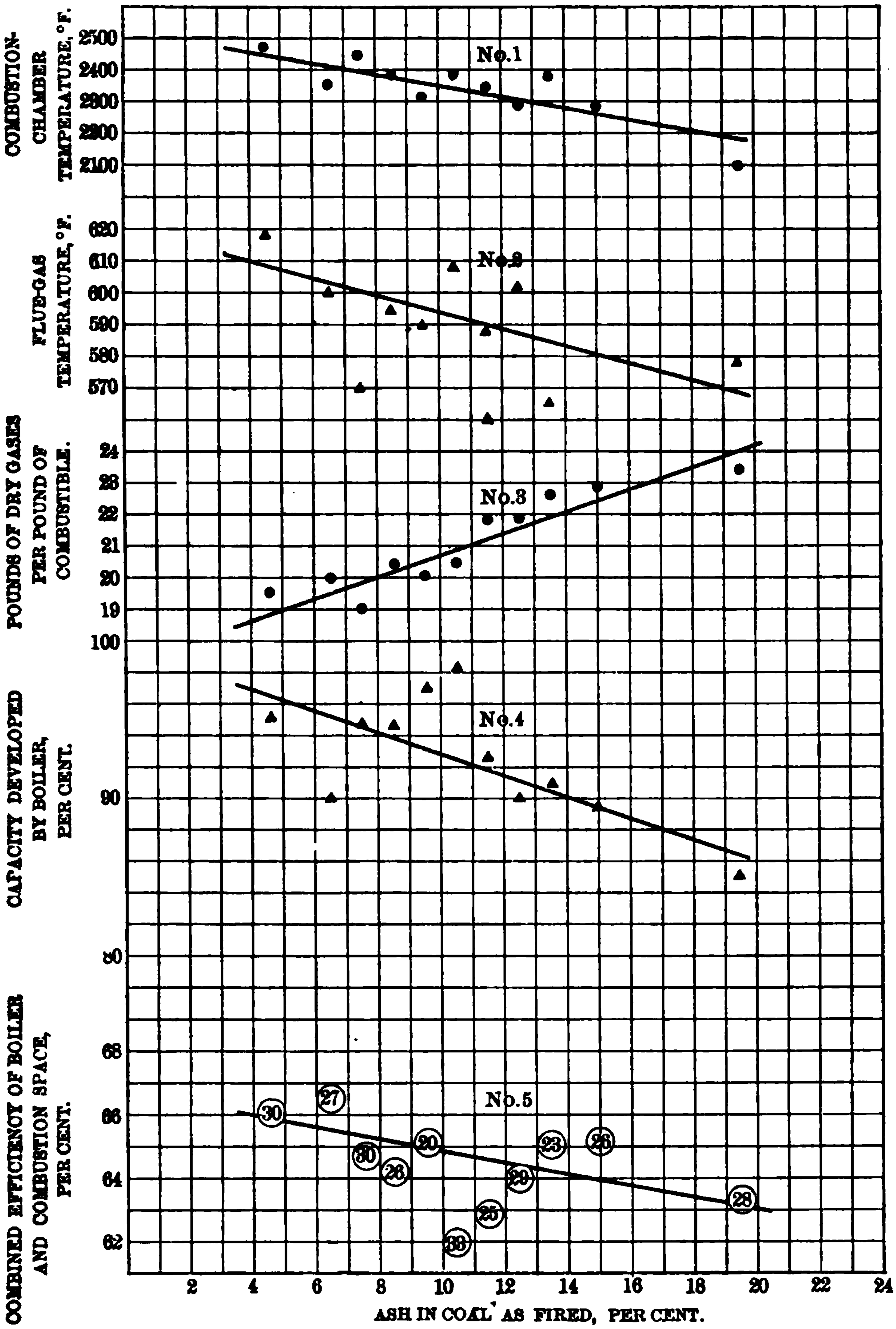


FIGURE 39.—Curves showing the relation of the percentage of ash in coal to: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); pounds of dry chimney gases per pound of "combustible" (No. 3); capacity developed by boiler (No. 4); combined efficiency of boiler and combustion space (No. 5). Tests 101 to 401.

removing the clinker from the grate the combustion is almost entirely suspended.

The curves of figure 39 confirm the statements made in the foregoing discussion.

Curve No. 3 indicates that more air is used to burn 1 pound of combustible when the ash in the coal increases. A larger air supply causes lower combustion-chamber temperature, and this in turn causes lower flue-gas temperature. These two facts are indicated by curves Nos. 1 and 2.

Curve No. 4 shows that, in general, the capacity of the boiler becomes lower when the percentage of ash in the coal increases.

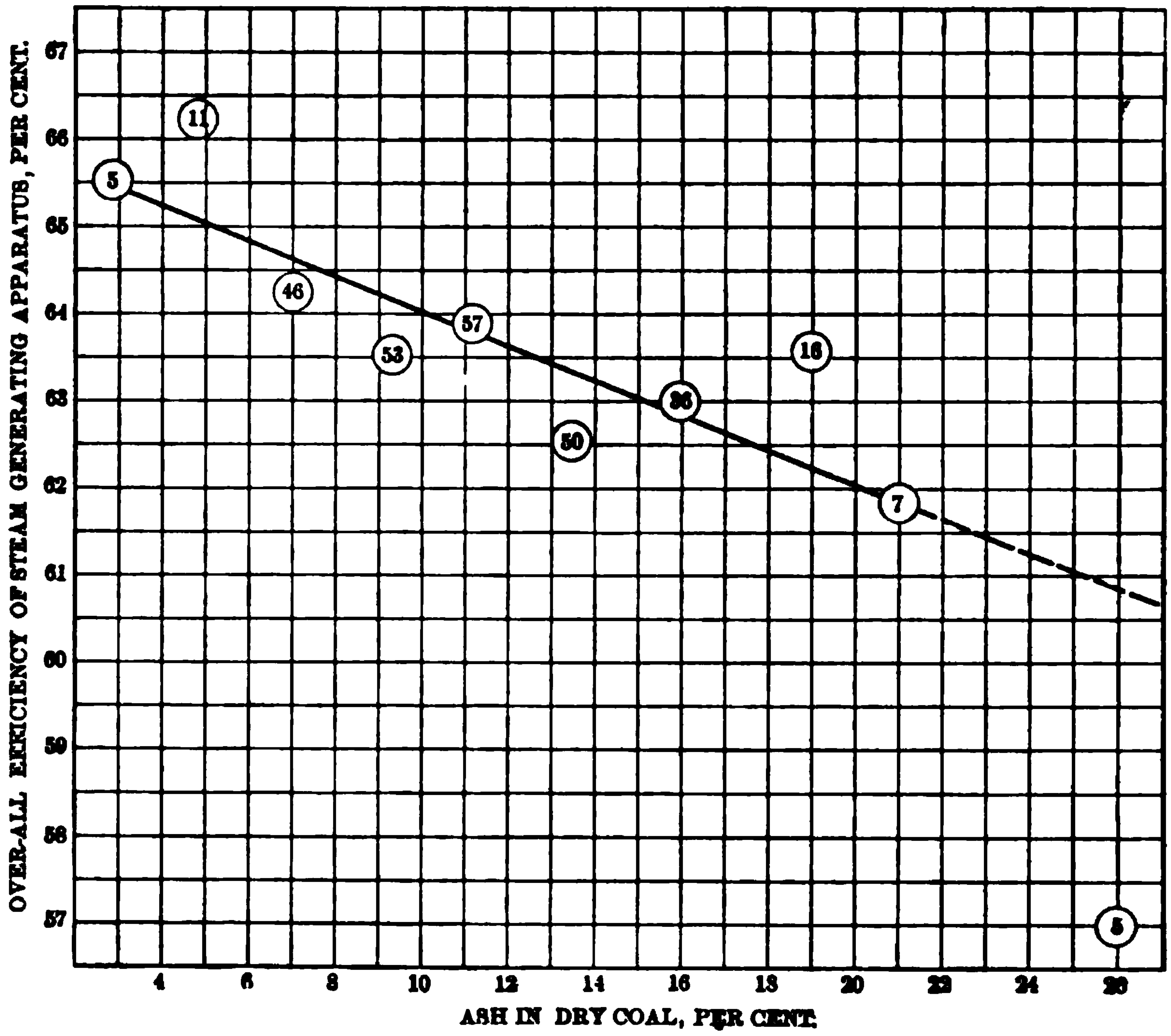


FIGURE 40.—Curve showing the relation of the percentage of ash in dry coal to the over-all efficiency of the steam-generating apparatus. Tests 120 to 410.

The drop in the combined efficiency of the boiler and furnace is rather small, indeed it is smaller than one would reasonably expect. It should be remembered that this efficiency does not include the grate, and therefore the losses shown by the curve do not include the combustible wasted in the ash and clinker in cleaning fires.

Attention is called to the rough relation shown by the individual points of curves Nos. 4 and 5; that is, when the capacity rises the efficiency drops. This relation has already been discussed in connection with figures 17 and 19.

Figure 40 shows the relation between the over-all efficiency and the percentage of ash in dry coal. This efficiency includes the grate and therefore the drop with the increase of the percentage of ash is more marked.

Figure 41 shows reversely the same relation as figure 40. The difference between the two figures is that figure 41 has been prepared by grouping the tests on the basis of the combined efficiency of the boiler and combustion space instead of on the percentage of ash. The chart shows that high over-all efficiencies were obtained with low-ash coal and that tests showing low efficiencies were mostly made with coals high in ash.

In the preparation of figures 39, 40, and 41 all tests made on boilers Nos. 1 and 2 were used, regardless of the kind of coal. It is very probable that the three figures show not only the effect of the percentage of ash in coal but also the effects of some other factors of the chemical composition of the coals. To eliminate these other factors

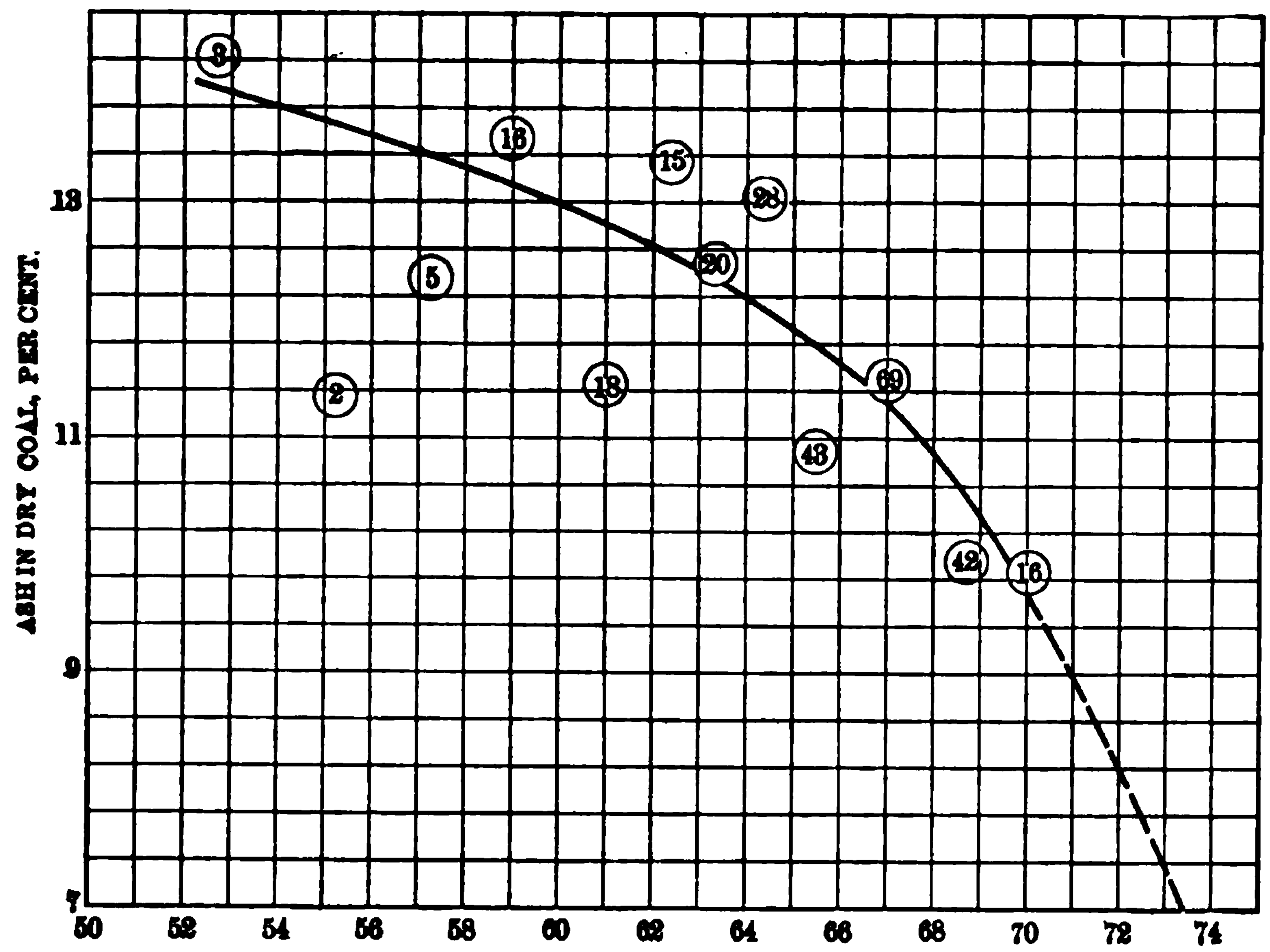


FIGURE 41.—Curve showing relation of the combined efficiency of the boiler and the combustion space to the percentage of ash in dry coal.

as far as possible, figures 42 and 43 were prepared from tests made on Illinois coals only. It is a known fact that coals coming from the same coal field are of somewhat the same chemical composition and, therefore, the steaming tests made on them are better fitted for comparison.

Curve No. 1 of figure 42 indicates that, in general, the combined efficiency of the boiler and combustion space drops only about 1.5 per cent when the ash in moist coal increases from 5 to 17 per cent. This is perhaps a smaller drop than one would expect. The numbers at each point of the curve give the highest and lowest combined efficiency of each group of tests. According to these numbers, high

efficiency may be obtained with coals containing any amount of ash from 5 to 17 per cent, but with coals of higher ash content the chances of obtaining good results are much less than with coals low in ash.

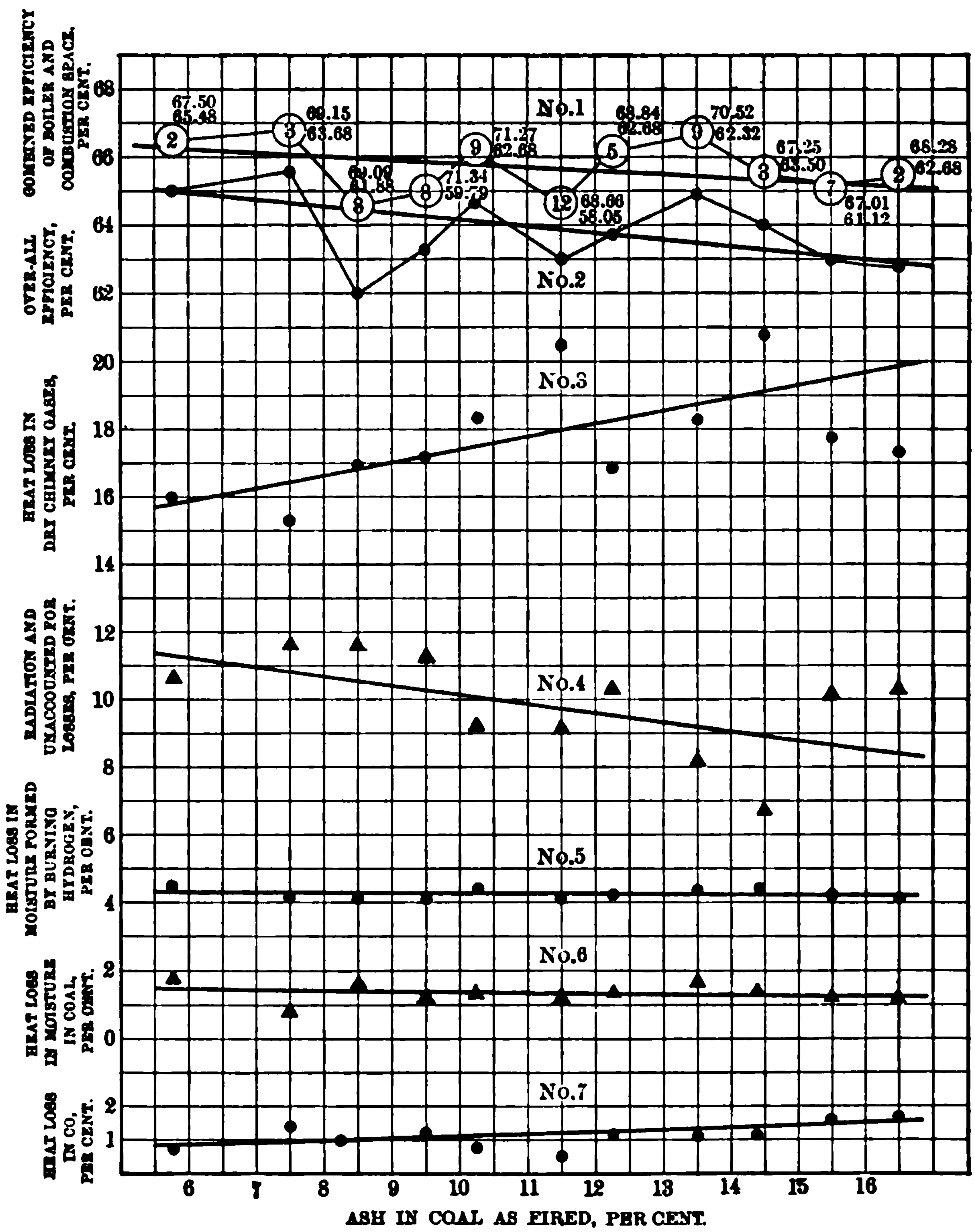


FIGURE 42.—Curves showing the relation of the percentage of ash in coal to: Combined efficiency of boiler and combustion space (No. 1); over-all efficiency of steam-generating apparatus (No. 2); heat loss in dry chimney gases (No. 3); radiation and unaccounted-for losses (No. 4); heat loss in moisture formed by burning hydrogen (No. 5); heat loss in moisture in coal (No. 6); heat loss in CO (No. 7). The ordinates of curves Nos. 1, 3, 4, 5, 6, and 7 are expressed as percentages of the heat of "combustible" ascending from the grate and, therefore, should add approximately to 100. Tests made with Illinois coals only.

The difference of slope between curves Nos. 1 and 2 indicates that more combustible is wasted in the refuse when the ash is high, a relation that is, of course, natural. The heat losses indicated by curves Nos. 5, 6, and 7 are very nearly constant for all percentages of ash within the limits investigated. The only losses that show any

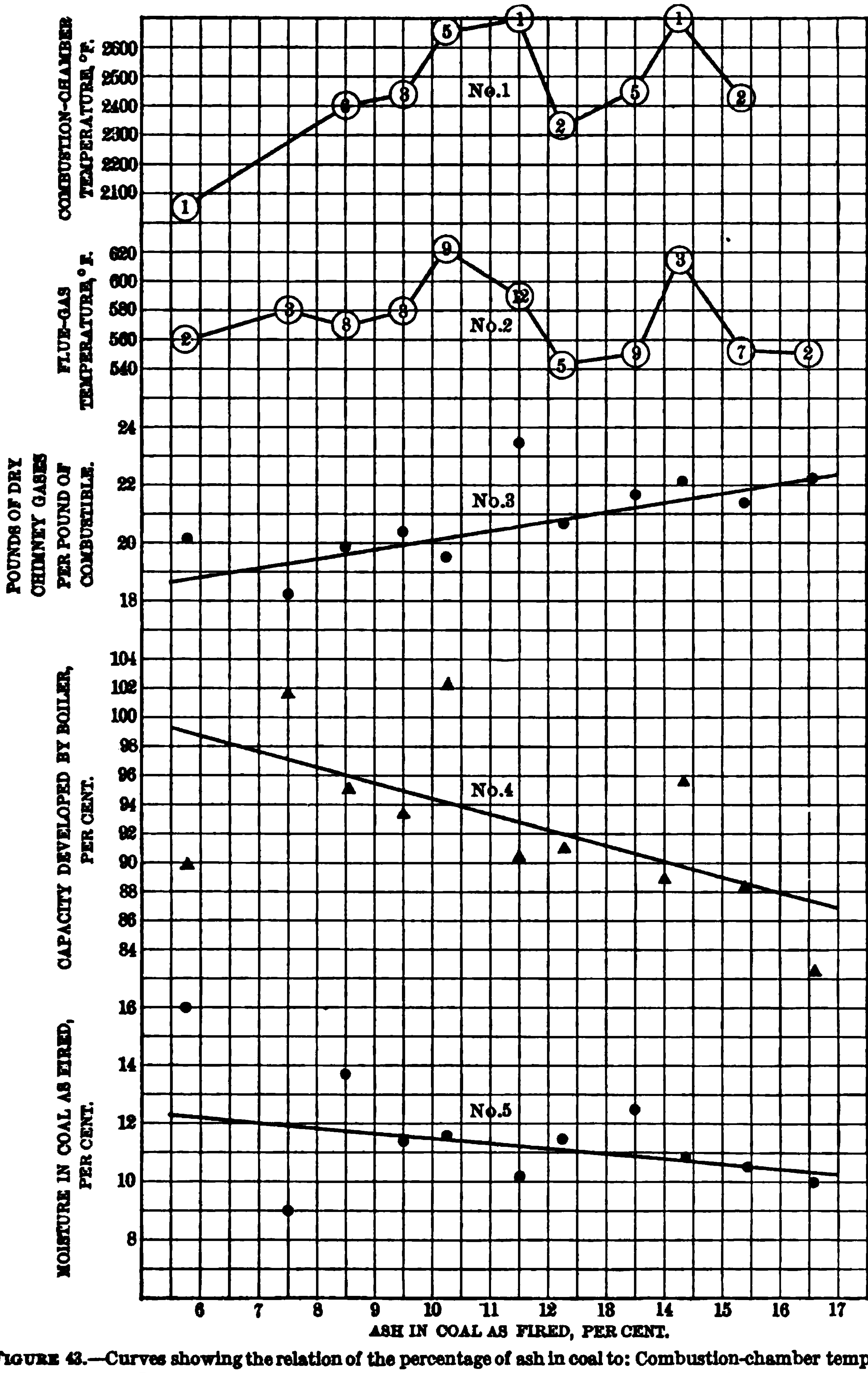


FIGURE 43.—Curves showing the relation of the percentage of ash in coal to: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); pounds of dry chimney gases per pound of "combustible" (No. 3); capacity developed by boiler (No. 4); moisture in coal as fired (No. 5). Tests made with Illinois coals only.

appreciable change when the percentage of ash in the coal increases are the chimney loss and the unaccounted-for losses. Their changes, however, are in opposite directions, so that they nearly neutralize each other. According to curve No. 3, the heat loss in the dry chimney gases increases about 4.5 per cent when the ash in the coal increases from 5 to 17 per cent. As shown by curves Nos. 2 and 3, figure 43, this greater heat loss up the stack is due entirely to a larger air supply. Curve No. 4, figure 42, indicates that the unaccounted-for heat losses decrease about 3 per cent when the ash in the coal increases from 5 to 17 per cent. Very likely the larger air supply causes a better combustion of the gases leaving the fuel bed, so that on the whole the completeness of combustion is improved by 3 per cent. This gain is undoubtedly possible only in the large combustion space of this particular furnace. The path of the gases from the fuel bed to the opening into the tube chamber is long enough for the combustible gases to mix with the excess of air and burn. The difference between the increase in the heat losses shown in curve No. 3 and the decrease shown in curve No. 4 is 1.5 per cent. This is about the same as indicated by curve No. 1.

Curve No. 5 of figure 43 shows that the per cent of moisture in the coal remains approximately the same for all percentages of ash and therefore does not enter into figures 42 and 43 as a factor influencing the results of steaming tests.

Curve No. 4, figure 43, shows that, in general, the capacity decreases with the increasing percentage of ash in the coal.

Considering the indication of the last two figures, one may conclude that, within the limits of 5 and 17 per cent, ash in the coal affects the efficiency of the steam-generating apparatus but little. The drop of 1.5 to 2 per cent in efficiency is entirely due to increased air supply.

The reduction in capacity is caused by lower possible rates of combustion and the suspension of furnace operation during the removal of clinker from the grate.

The above conclusions are applicable with certainty only to a hand-fired Heine furnace.

EFFECT OF MOISTURE IN COAL ON THE RESULTS OF TESTS.

Coal when burned always contains some moisture even though the coal may appear perfectly dry. Absolutely dry coal is known only to the chemist, and he finds it difficult to keep it in that state because dry coal absorbs moisture readily from the atmosphere.

Various kinds of coals hold, without appearing wet, different percentages of moisture. High-grade eastern bituminous coal may run 3 to 5 per cent in moisture, while the North Dakota lignites hold 40 or more per cent of moisture when mined.

When coal is used for steaming purposes the effect its moisture has on the economic results depends on the quantity of moisture

contained in the coal. Though in moderate percentage the moisture may be harmless or may even prove beneficial, in large quantities it undoubtedly reduces the useful effect of the heat in the coal. The term "moderate percentage" may have different values with different coals. We often hear of a perfectly sane engineer who claims he gets better results in his steam plant by wetting his coal. It is possible that the presence of a certain amount of water vapor in the furnace facilitates combustion of the volatile combustible. The heat lost in the free moisture of the coal is not as large as it may at first appear to be; thus with coals containing 10 per cent moisture

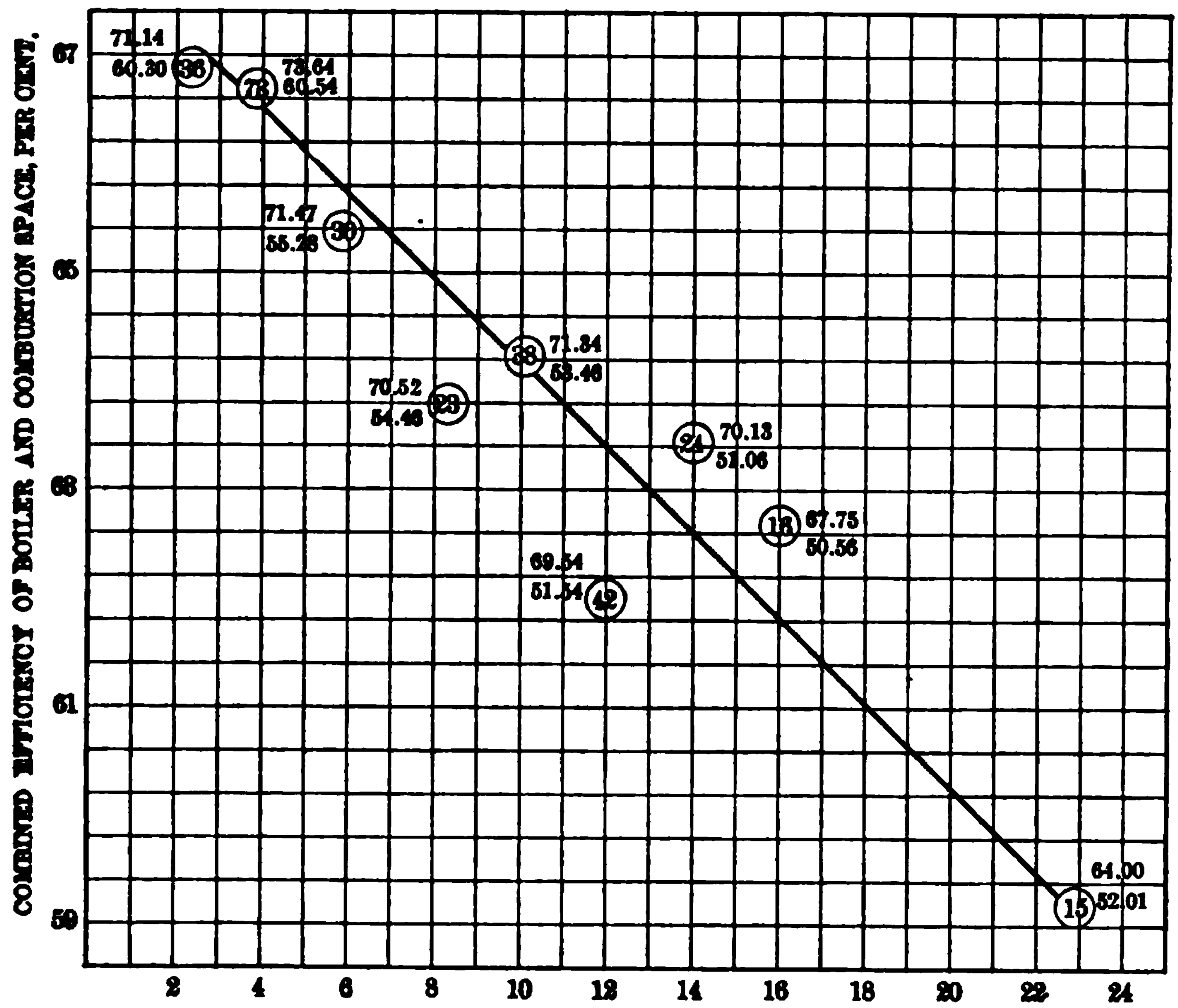


FIGURE 44.—Curve showing the effect of moisture in coal on the combined efficiency of boiler and combustion space. Tests 101 to 410.

the heat loss accountable to the moisture is about 1 per cent, with coals containing 17 per cent moisture the heat loss is about 2 per cent. With the ordinary amount of hydrogen in the coal the heat loss in the moisture formed by the burning of the hydrogen is about 4 per cent. It is apparent that if the moisture in the coal is increased by wetting until it is from 10 to 15 per cent, the increase in the heat loss in free moisture is less than 1 per cent, a loss that may be more than offset by obtaining better combustion.

Of course, with lignites high in moisture and low in heat value the heat loss accountable to moisture may reach as high as 10 per cent of the total heat in the coal.

If coal is purchased merely on the weight basis, moisture is objectionable because the buyer pays a good price for something that has no value to him. In this respect the moisture is as undesirable as the ash. In the boiler room moisture has the advantage over ash in that it does not need to be removed from the fires and the boiler room.

Figure 44 has been platted to show the effect of the moisture in coal on the combined efficiency of the boiler and the combustion space. All tests made on boilers Nos. 1 and 2 were used in its preparation regardless of the nature of the coals. This fact makes the curve somewhat misleading, inasmuch as the coals high in moisture contain also high percentages of ash, so that the effect shown by the curve is to some extent the combined effect of the moisture, ash, and perhaps of some other factors.

The numbers at each point indicate the highest and lowest efficiency obtained within each group of tests.

Figures 45 and 46 were prepared from tests made with Illinois coals only. By using coals from one coal field the effect of the chemical composition of the coal is nearly eliminated, and the curves more nearly show the moisture effects not destroyed or exaggerated by other factors. The two figures were prepared by grouping the tests on the basis of the percentage of moisture in the coal.

The numbers near the points of curve No. 1, figure 45, denote the highest and the lowest combined efficiencies of the boiler and the combustion space of each group of tests. The ordinates of curves Nos. 1, 3, 4, 6, and 7 show how the heat of the combustible ascending from the grate has been distributed. The heat is expressed in percentages and therefore the ordinates of these six curves should add to 100. Ordinates of curve No. 2 are expressed in percentages of the heat of the coal fired on the grate.

Curve No. 1 shows that as the moisture in the coal increases from 7 to 16.5 per cent the combined efficiency of the boiler and combustion space drops about 4.5 per cent. According to curves Nos. 3 to 7 this increased heat loss of 4.5 per cent can be accounted as follows:

The heat loss in the dry chimney gases is increased about 1.7 per cent, through larger air supply and slightly higher flue-gas temperature, as is shown by curve No. 3, figure 45, and curves Nos. 2 and 3, figure 46. As shown by curve No. 4, figure 45, the unaccounted-for losses increase about 1.5 per cent. This increase in the heat loss is perhaps largely due to less complete combustion, although this explanation is not quite confirmed by curve No. 7. It is also possible that a small part of this larger heat loss is due to increased radiation losses. Curve No. 4, figure 46, shows that the capacity drops as the moisture in coal increases. The amount of heat radiated from the boiler and its setting is about the same in quantity, so that as the capacity drops the radiation loss becomes larger.

Curve No. 5, figure 45, shows that about 0.5 per cent of the increased heat loss can be ascribed to a somewhat larger loss in the moisture formed by burning the hydrogen.

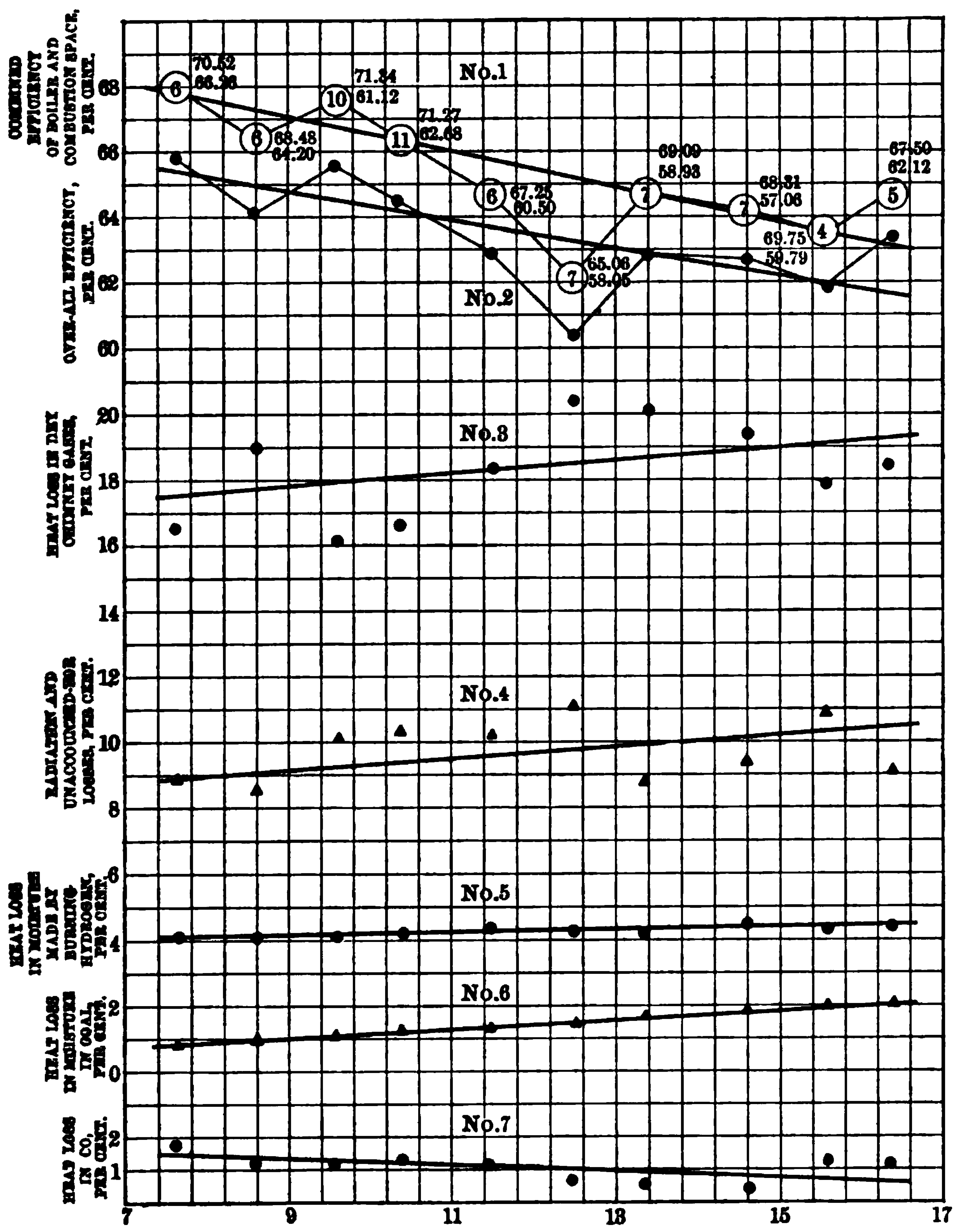


FIGURE 45.—Curves showing the effect of moisture in coal on: Combined efficiency of the boiler and the combustion space (No. 1); over-all efficiency of the steam-generating apparatus (No. 2); heat loss in dry chimney gases (No. 3); radiation and unaccounted-for losses (No. 4); heat loss in moisture formed by burning hydrogen (No. 5); heat loss in moisture in coal (No. 6); heat loss in CO (No. 7). Tests made with Illinois coals only.

Curve No. 5, of figure 46, indicates that the average percentage of ash for each group of tests remains nearly constant as the moisture in the coal increases, and, therefore, the effect of the ash is nearly absent in the last two figures.

From figures 45 and 46 one may conclude that moisture in the coal reduces the efficiency of the steam-generating apparatus by (*a*)

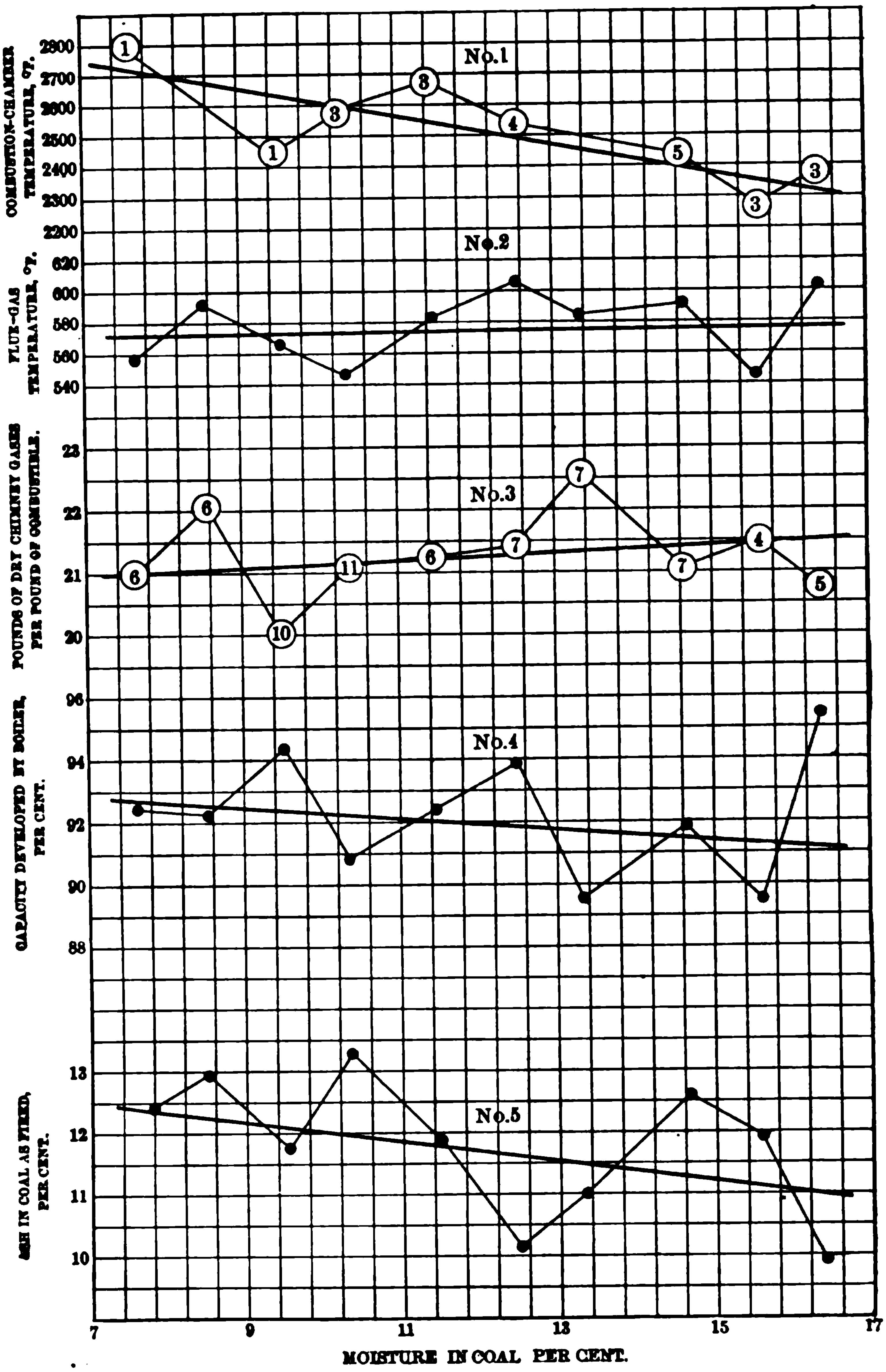


FIGURE 46.—Curves showing the relation of the percentage of moisture in coal to: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); pounds of dry chimney gases per pound of combustible (No. 3); capacity developed by boiler (No. 4); ash in coal as fired (No. 5). Tests made with Illinois coals only.

increasing the heat carried away in the dry chimney gases, due to larger air supply and slightly higher flue-gas temperature; (*b*) by

increasing the heat carried away by the moisture itself; and (c) by the escape of a larger quantity of free hydrogen.

The reduction of the capacity of the boiler is caused by a lower rate of combustion caused probably by the dilution of the oxygen by the large quantity of water vapor. (See section on "Principles involved in the combustion of coal in boiler furnaces," pages 330 to 340.")

Comparison of figures 42 and 45 brings out the fact that moisture in the coal reduces the efficiency of the steam-generating apparatus more than the same percentage of ash. This fact may appear strange until one stops to think that as long as all the combustible is burned with economical air supply the ash itself has no heat-absorbing properties. On the other hand, water vapor, besides having some property of hindering the rate of combustion, has great heat-absorbing capacity because of its high latent heat and its high heat of formation or decomposition.

EFFECT OF SULPHUR ON RESULTS OF TESTS.

Sulphur is an undesirable element in coal. It often occurs combined with iron as iron pyrites. In such combination it is worthless as fuel, although in a free state it has a heating value of about 4,000 B. t. u. per pound. Pyrites can be readily recognized by its heavy weight and bright brass-like color. Sulphur is also contained in coal in combination with calcium as gypsum or calcium sulphate. This mineral occurs in thin white flakes more or less transparent. Of the two sulphur compounds the pyrites is usually contained in coal in larger quantity, and is objectionable on account of its increasing the tendency of the coal to clinker. The clinkering is particularly bad if the percentage of ash is small in proportion to the sulphur. Under such conditions the ash appears especially fusible and forms thin layers of solid clinker, which effectively stop the flow of air through the fuel bed and permit the grate bars to become heated. On account of the lack of flow of air through the grate the clinker is kept in a molten state and runs down between the grate bars. At such high temperatures the sulphur attacks the iron of the grate bars. The grate may be destroyed in the course of a few days by the corrosive action of the molten clinker and the excessively high temperature.

When such clinkers form, any attempt to loosen them with a slice bar fails and only laborious cleaning of the fires will temporarily improve the conditions.

When coals which clinker badly are burned on a plain or a rocking grate the clinker may be usually prevented from running between the grate bars by blowing steam under the grate. The explanation given for this effect of the steam on the clinkers is that the steam when passing the hot clinkers is decomposed into hydrogen and oxy-

gen. This decomposition is a cooling process and the heat needed to effect it is taken from the hot clinker, thus cooling the latter below its melting point.

The use of steam as a remedy for clinker troubles was found to work satisfactorily with most of the coals, particularly those high in ash and sulphur. However, for coals very low in ash, this remedy

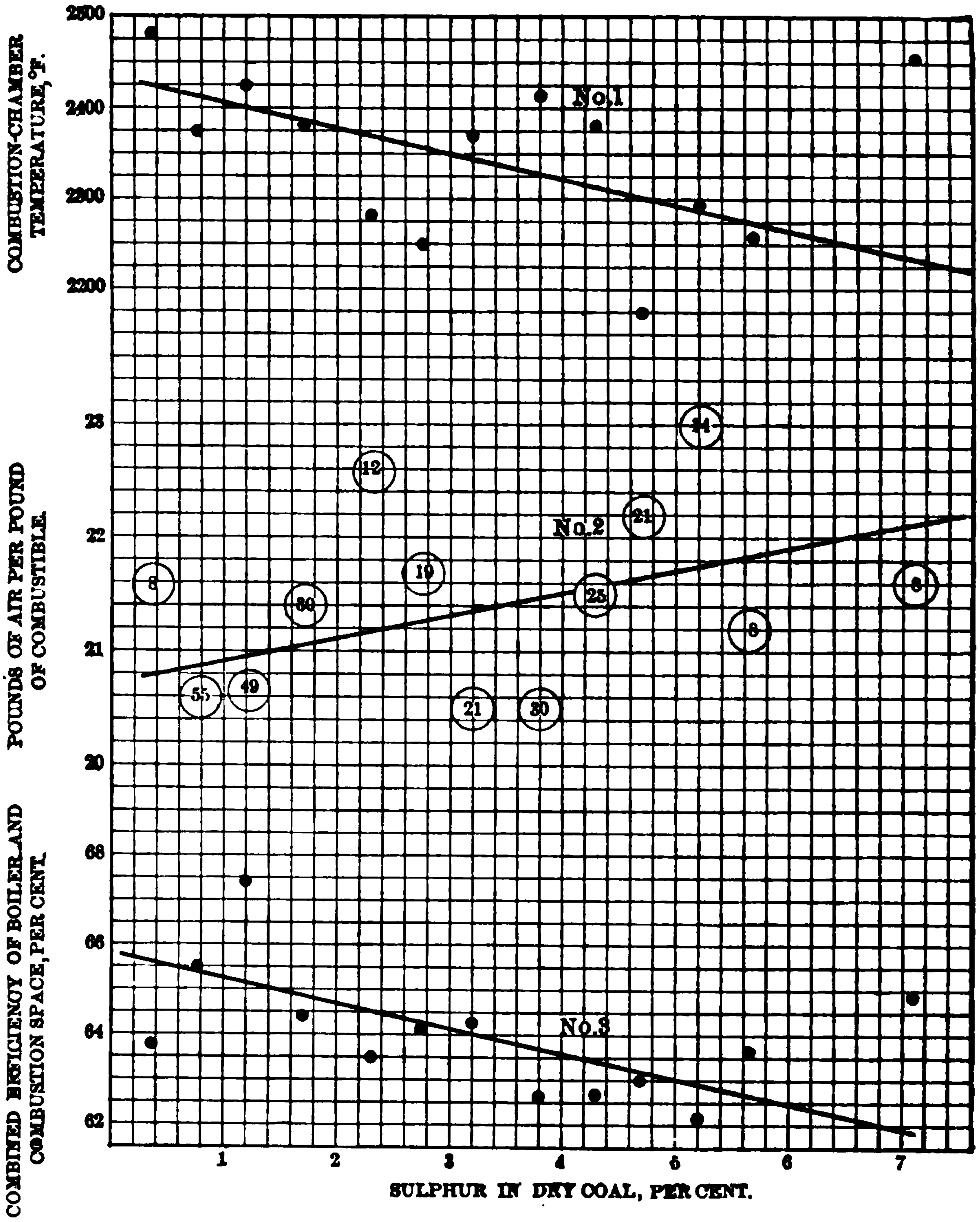


FIGURE 47.—Curves showing the effect of the percentage of sulphur in dry coal on: Combustion-chamber temperature (No. 1); pounds of dry chimney gases per pound of "combustible" (No. 2); combined efficiency of boiler and combustion space (No. 3). Tests made in boilers Nos. 1 and 2; all coals included.

sometimes proved insufficient. In such cases crushed limestone, spread over the thin, clean fuel bed immediately on starting the tests, generally prevented trouble from running clinkers.

To make a general statement, it may be said that the tendency of a coal to clinker varies directly with the percentage of sulphur and inversely with the percentage of ash in the coal.

Sulphur in coal affects the economy of the steam-generating apparatus in that it forms clinkers which hinder proper distribution of air. Thus, sulphur may be the cause of local excess or deficiency of air and the accompanying heat losses in the dry chimney gases or in incomplete combustion.

To find what influence sulphur in coal has on the results of tests, figure 47 has been prepared from all the tests made on boilers Nos. 1 and 2, regardless of the kind of coal. The tests were grouped on the basis of the percentage of sulphur in the coal.

According to curve No. 3, figure 47, the combined efficiency of the boiler and combustion space drops about 3 per cent as the sulphur in dry coal increases from 0.5 to 6 per cent. This drop in the efficiency is largely due to the increased air supply, as shown by curve No. 2.

Inasmuch as figure 47 is prepared from tests made with all grades of coals, the curves may show the effects of other factors besides that of the sulphur. These other factors may exaggerate or neutralize the effect of sulphur so that the indication of the curves may be somewhat misleading. In order to eliminate most of these disturbing factors and to get at the effect of the sulphur alone, figures 48 and 49 were prepared from tests made with Illinois coals. Figure 48 shows graphically the average distribution of heat as given in the heat balance in Table 4.

Curve No. 1, figure 48, shows that the combined efficiency of the boiler and combustion space drops about 3 per cent when the sulphur in coal increases from 0.5 to 5.5 per cent, which is about the same drop as shown by curve No. 3, figure 47. Of this 3 per cent about 2.5 can be charged to increased heat loss in the dry chimney gases because of a larger air supply. The remaining 0.5 per cent can be ascribed to slightly higher heat losses in the moisture in coal and that formed by burning the hydrogen of the combustible. Neither the unaccounted-for losses, curve No. 4, nor the CO, curve No. 7, shows any increase of incomplete combustion.

Curves Nos. 1 and 2 are nearly parallel, indicating that the average loss of combustible in the refuse is about constant, no matter what the percentage of sulphur in the coal may be.

Curve No. 3, figure 49, indicates a general drop of about 8 per cent in the capacity of the boiler as the sulphur in the coal increases from 0.5 to 5.5 per cent. Undoubtedly the increased amount of clinker formed with larger percentages of sulphur reduces the rate of combustion, thereby decreasing the capacity. The lower rates of combustion at the right of the figure tend to improve the completeness of combustion, as suggested by curves Nos. 4 and 5, figure 48.

Curves Nos. 4 and 5, figure 49, indicate higher percentages of ash and moisture in the coal. Possibly the increase of these two con-

stituents partly accounts for the drop in efficiency shown by curve No. 1, figure 48.

Figure 50 has been prepared by grouping the tests on the basis of the

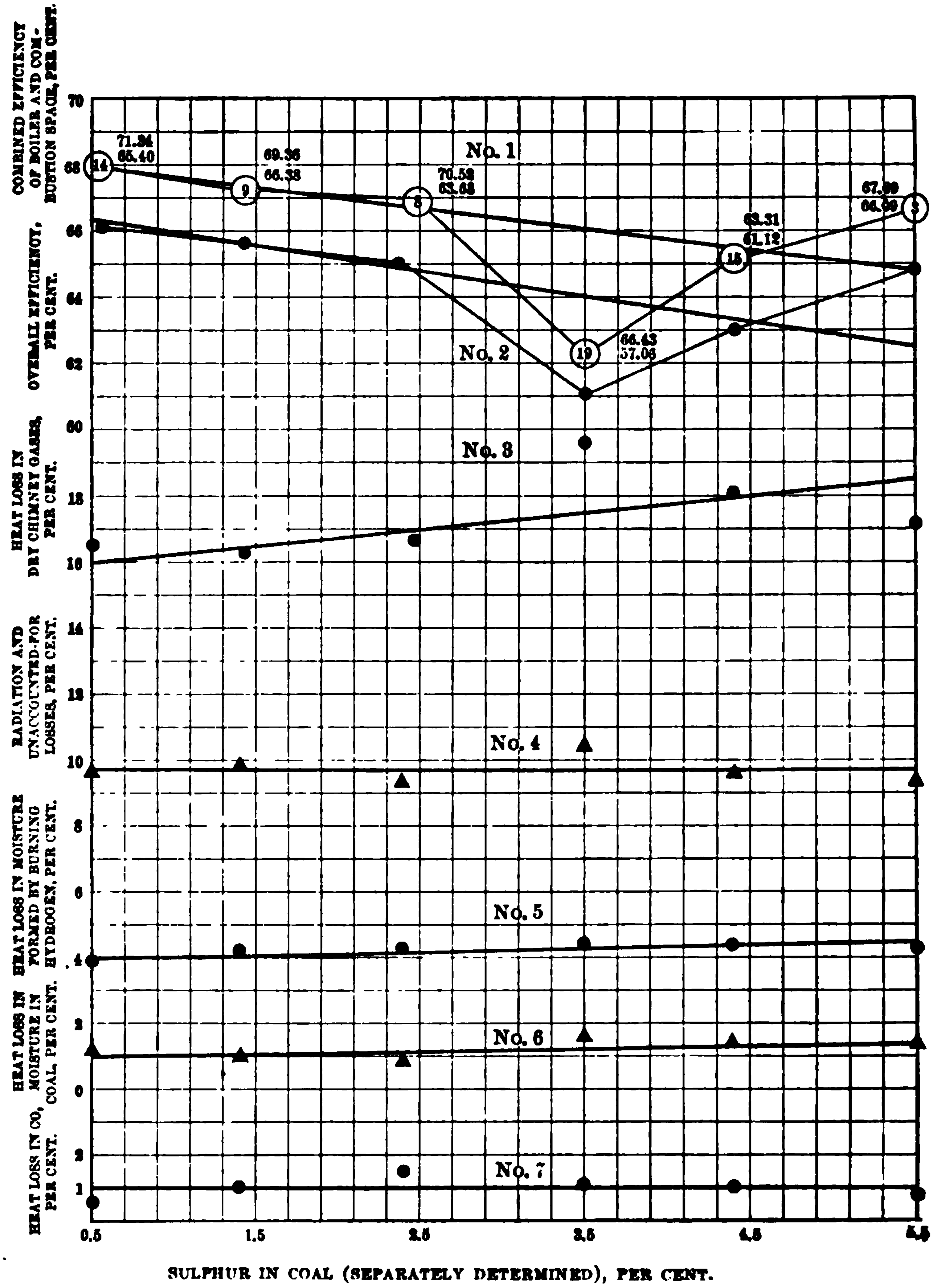


FIGURE 48.—Curves showing the effect of the percentage of sulphur in coal on: Combined efficiency of boiler and combustion space (No. 1); over-all efficiency of the steam-generating apparatus (No. 2); heat loss in dry chimney gases (No. 3); radiation and unaccounted-for losses (No. 4); heat loss in moisture formed by burning hydrogen (No. 5); heat loss in moisture in coal (No. 6); heat loss in CO (No. 7). Tests made with Illinois coals only.

combined efficiency of the boiler and the combustion space. The object of curve No. 1 is to show whether, in general, tests showing high efficiency were made with coals low in sulphur and low-efficiency tests with coals high in sulphur. The finding is that the tests showing the

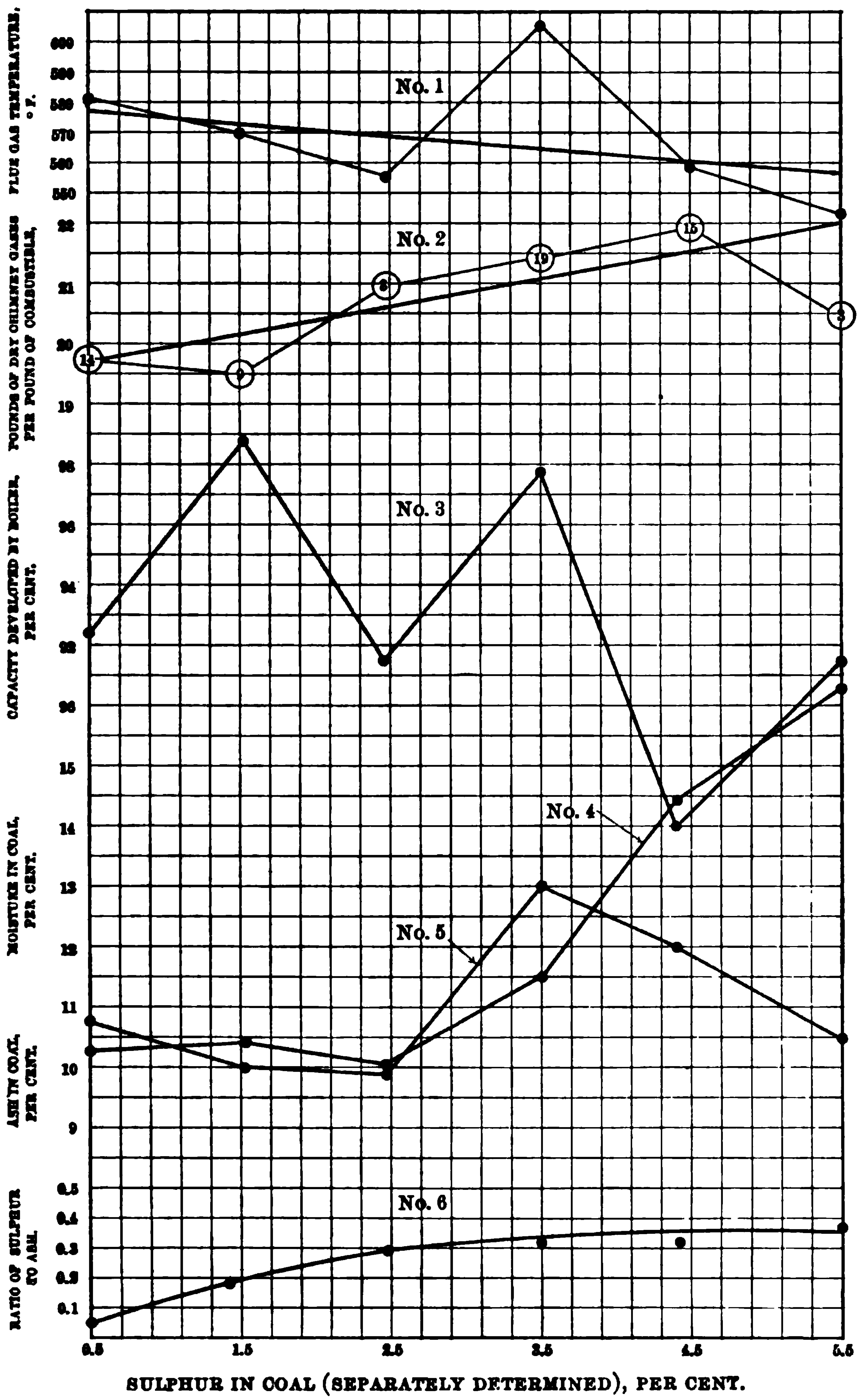


FIGURE 49.—Curves showing the relation of the percentage of sulphur in coal to: Flue-gas temperature (No. 1); pounds of dry chimney gases per pound of "combustible" (No. 2); capacity developed by boiler (No. 3); ash in coal (No. 4); moisture in coal (No. 5); ratio of sulphur to ash (No. 6). Tests made with Illinois coals only. Tests 101 to 125 rejected.

highest efficiency were made with coals low in sulphur, but that there is no difference in the sulphur contents between coals which gave medium and low efficiencies.

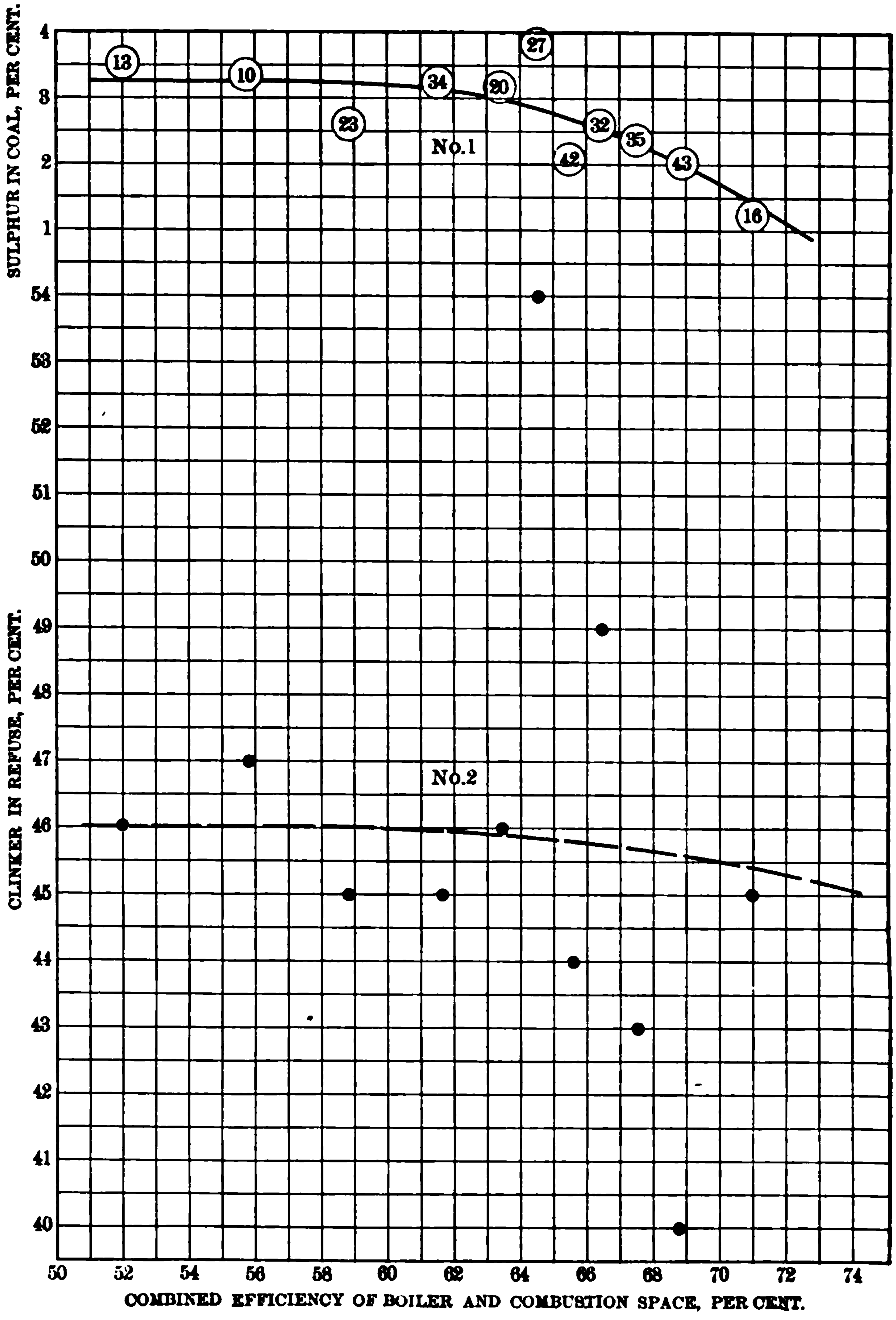


FIGURE 50.—Curves showing the relation of the combined efficiency of the boiler and the combustion space to the percentage of sulphur in coal (No. 1) and the percentage of clinker in refuse (No. 2). Tests made on boilers Nos. 1 and 2; all coals included.

The lower group of points (No. 2) is so scattered that it is impossible to draw a curve through them which would show a logical relation. The indication is that there is no definite relation between the amount of clinker and the efficiency. Probably the character of the clinker

has more to do with the results of a test than the quantity. Doubtless a heavy solid clinker is much more injurious than a light porous one.

The lower group of points (No. 2) of figure 51 show a similar lack of relation between the quantity of clinker and the combined efficiency. It would be unwise to claim that the best results are obtained when about half of the refuse comes out of the furnace in the form of clinker, which is about what the points indicate.

Curve No. 1, figure 51, confirms the statement made elsewhere that sulphur in the coal increases the tendency of the coal to clinker. Tests showing the highest amount of clinker were made with coals having the highest percentages of sulphur.

From the indication of figures 47 to 51, inclusive, we can deduce the following conclusions:

Sulphur in a coal increases its tendency to clinker. The presence of clinker on the grate hinders a proper distribution of air through the fuel bed in such a way that more air is used to burn 1 pound of combustible than is required to obtain good economy. The excess of air is the chief cause of the heat loss incurred by the sulphur in the coal; on account of the large supply of air and the reduced rate of combustion the completeness of combustion is not affected by the sulphur to an appreciable extent.

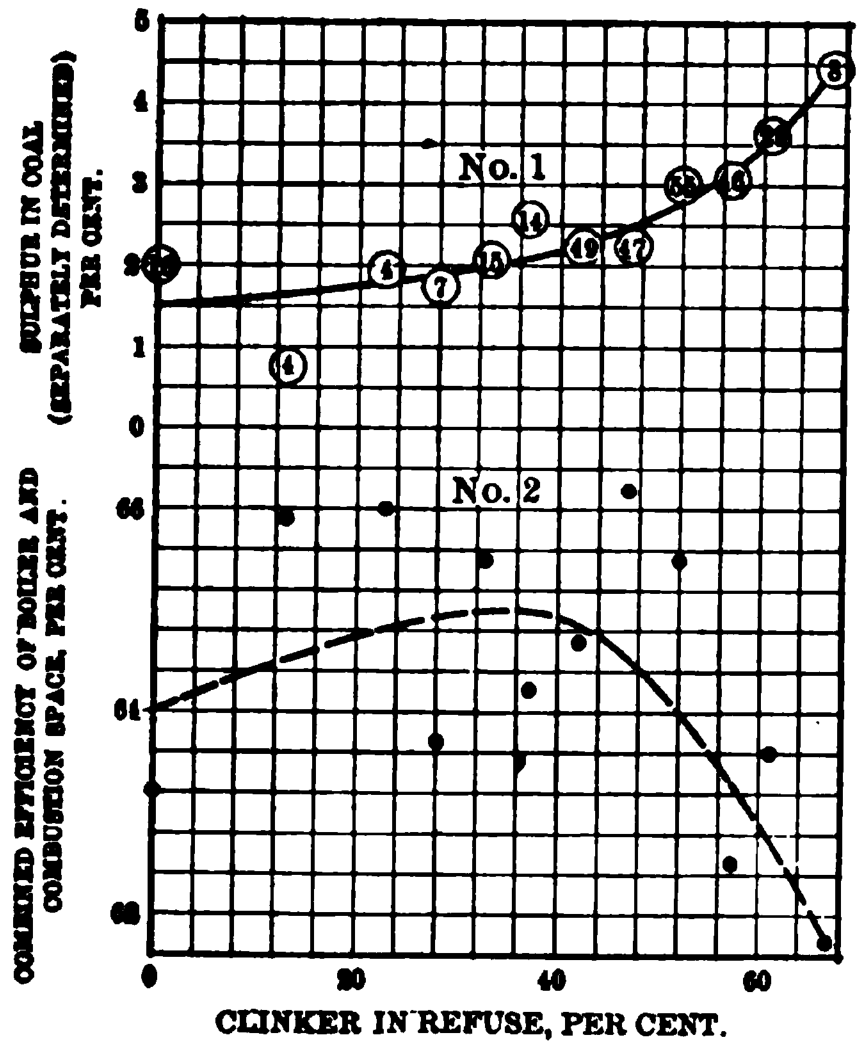


FIGURE 51.—Curves showing the relation of the percentage of clinker in refuse to the percentage of sulphur in coal (separately determined) (No. 1); and to the combined efficiency of the boiler and the combustion space (No. 2). Tests made on boilers Nos. 1 and 2; all coals included.

Sulphur in the coal reduces the rate of combustion, and thereby reduces the capacity of the boiler.

RELATION BETWEEN OXYGEN IN COAL AND THE COMBINED EFFICIENCY OF THE BOILER AND THE COMBUSTION SPACE.

According to figure 52, the combined efficiency of the boiler and the combustion space drops about 8 per cent when the oxygen in the coal increases from 3 to 15 per cent. This relation is purely incidental, as no logical course of reasoning can demonstrate that the oxygen in the coal would in any way be a cause of large excess of air or incomplete combustion, which are the two chief sources of loss in the operation of a steam-generating apparatus. Undoubtedly the drop in the efficiency is caused directly by the increasing percentages of

moisture and ash in the coal. Consultation of the chemical composition of the coals given in columns 39 to 49, inclusive, Table 4, will reveal the fact that coals high in oxygen always contain high percentages of moisture or ash, or both.

EFFECT OF VOLATILE CARBON ON THE COMBINED EFFICIENCY OF THE BOILER AND THE COMBUSTION SPACE.

The volatile combustible of coal consists almost entirely of hydrogen and carbon. The percentage of hydrogen varies with different coals from 3.5 to 5 per cent and is therefore approximately constant

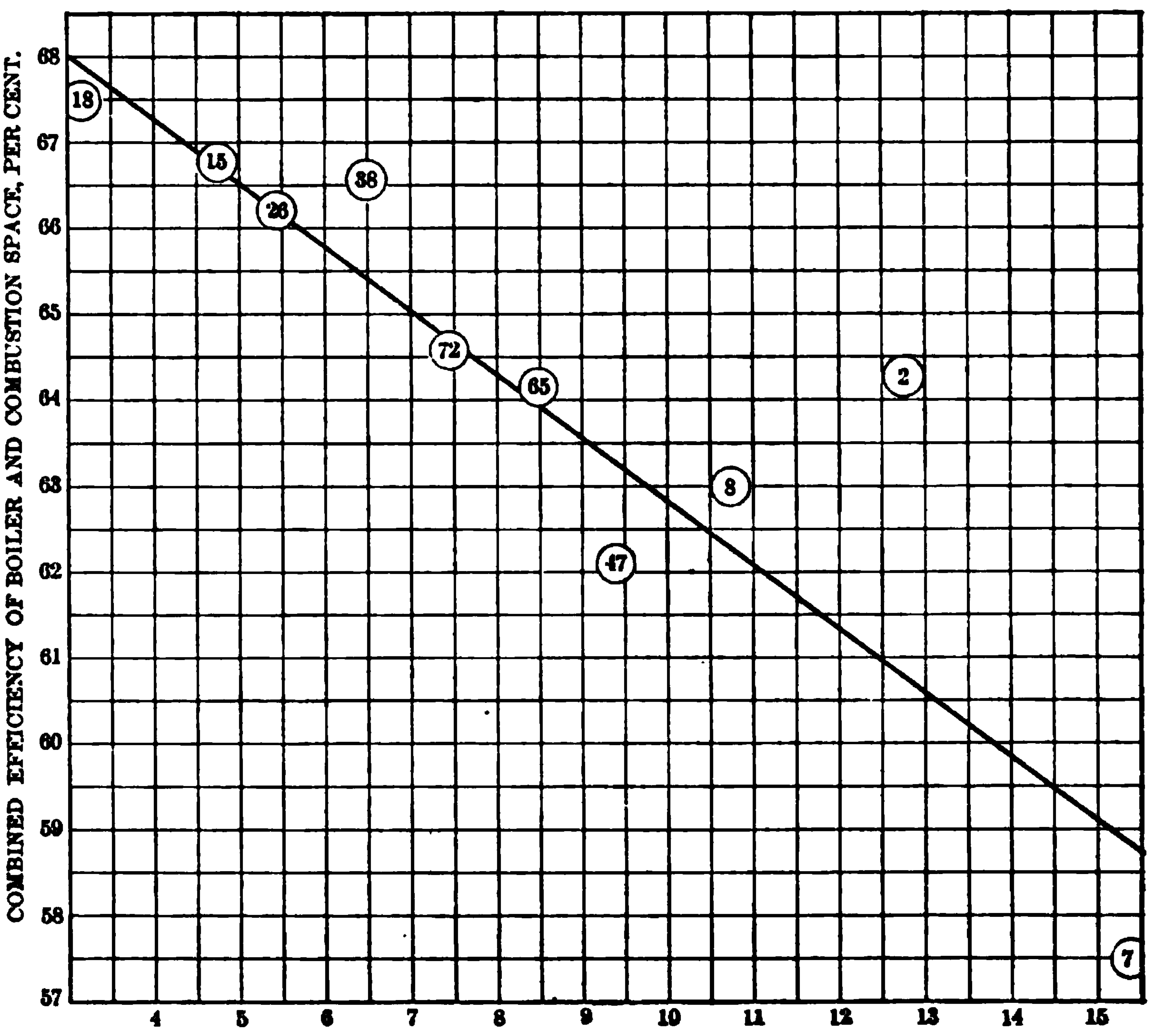


FIGURE 52.—Curve showing the relation of the percentage of oxygen in moisture and ash free coal to the combined efficiency of the boiler and the combustion space. Tests made on boilers Nos. 1 and 2; all coals included.

for all coals. The volatile carbon, on the other hand, varies in different coals from 7 to 35 per cent. Therefore one can say that the percentage of volatile combustible depends almost entirely on the amount of volatile carbon; the higher the volatile carbon the higher is the volatile combustible. It is obvious that when the volatile combustible varies in quantity it also varies in chemical composition; that is, the higher a coal runs in volatile matter the heavier are the hydrocarbons constituting the volatile combustible. The heavy hydrocarbons are very difficult to burn within any limited

combustion space. Hence when the volatile matter in coal increases not only is there more volatile combustible to burn, but the latter consists of such compounds as present serious difficulties in burning. For these reasons one may expect tests made with coals high in volatile carbon to show less complete combustion and therefore lower efficiency than tests made with coals low in volatile carbon. That such a relation exists is shown by figure 53.

The figure indicates that as the volatile carbon increases from 6 to 40 per cent, the combined efficiency of the boiler and the combustion space drops from 67 to 58 per cent. This drop in the combined

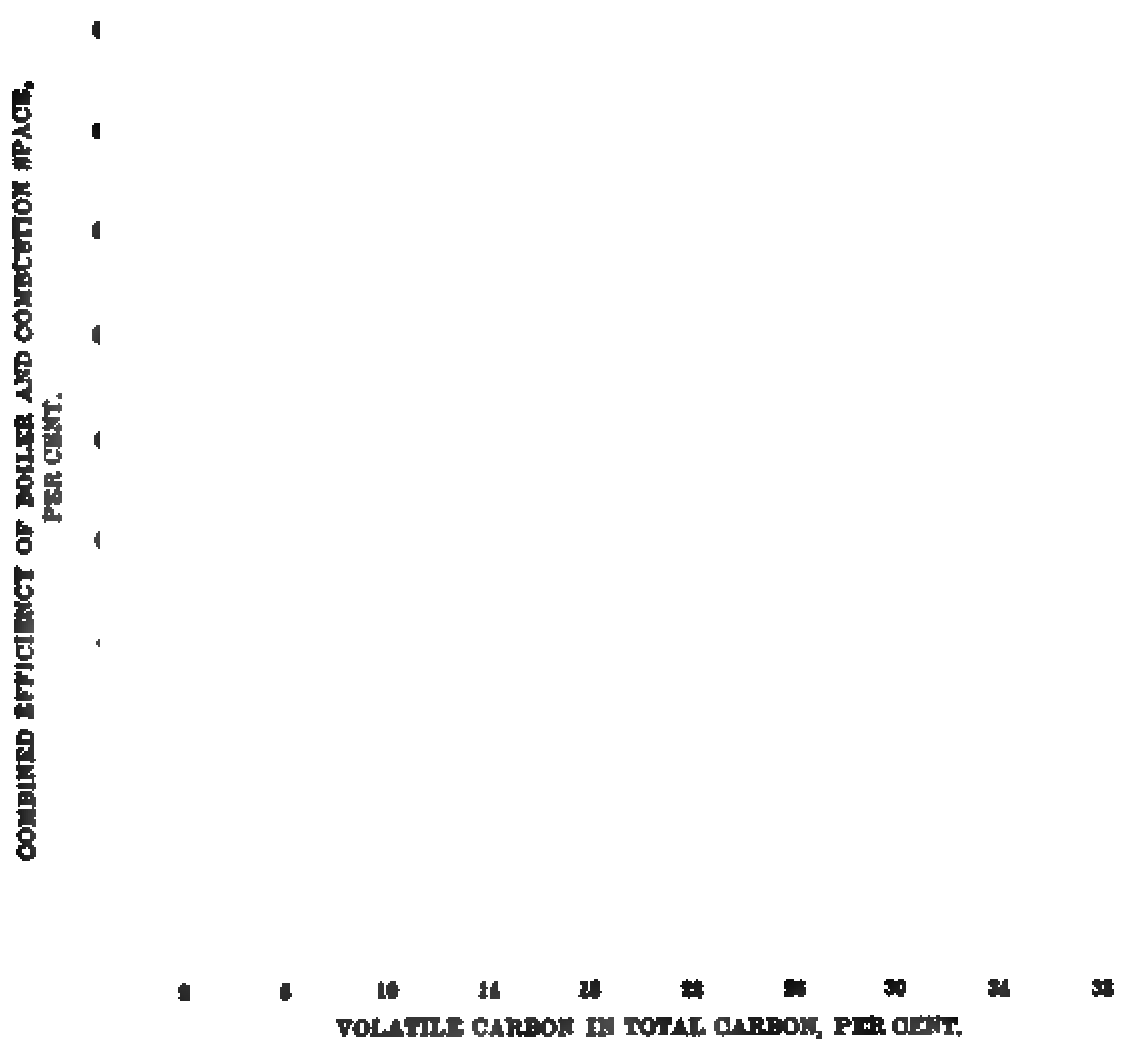


FIGURE 53.—Curve showing the effect of volatile carbon on the combined efficiency of the boiler and the combustion space. Tests made on boilers Nos. 1 and 2; all coals included.

efficiency, shown in figure 53, is not, however, entirely due to the increasing percentage of volatile carbon.

Perhaps one-half to two-thirds of it is caused by the increasing percentages of moisture and ash. Coals high in volatile carbon generally contain high percentages of moisture and ash.

RELATION OF CARBON-HYDROGEN RATIOS TO RESULTS OF TESTS.

In Professional Paper 48, of the United States Geological Survey, page 168, M. R. Campbell proposed a classification of coals on the basis of the ratio of carbon to hydrogen. His reason for selecting

this basis was that carbon and hydrogen are the chief constituents of the combustible matter of coal and, therefore, any classification of coals to be of any practical and scientific value must use some combination of these two elements for its basis. He considered the ratio of carbon to hydrogen as the best combination. Classification of coals on this basis is perhaps a fair one for scientific purposes. It is precise and is equally applicable to all classes of coals from the highest grade of anthracite to the brown lignites. It should also be useful as a basis on which to estimate the value of various types of coals for steaming purposes.

The study of previous charts has revealed the fact that the three most important variable heat losses in the process of steam generation are, in order:

(*a*) Heat loss in excessive supply of air.

(*b*) Heat loss in incomplete combustion.

(*c*) Heat carried away in the moisture of coal.

It has been shown that the loss under (*a*) increases considerably with the percentage of ash and sulphur and slightly with the moisture in coal.

The loss under (*b*) increases with the percentage of volatile combustible and also with the moisture in coal. It has been suggested that in the latter case incomplete combustion is increased because of the escape of larger quantities of free hydrogen.

The loss under (*c*) increases directly with the moisture in coal.

The most useful classification giving the value of coals for steaming purposes would be one based on all the above factors, namely, ash, sulphur, moisture, and volatile combustible.

Since the volatile combustible increases as the carbon-hydrogen ratio becomes smaller and, also, if hydrogen is taken in percentage of moist coal, the moisture in coal increases as the ratio decreases, classification on the carbon-hydrogen basis includes directly two factors which affect the efficiency of the steam-generating apparatus. Generally, coals of high carbon-hydrogen ratio contain low percentages of ash, and coals having low carbon-hydrogen ratios have high percentages of ash. Therefore classification on the carbon-hydrogen ratio may include incidentally the ash factor and, perhaps, also, the sulphur. One would, therefore, rightly expect a rise in the combined efficiency of the boiler and the combustion space with an increasing carbon-hydrogen ratio.

R. H. Kuss and H. W. Weeks, formerly members of the steam-engineering section, have classified most of the coals tested with boilers Nos. 1 and 2, and prepared figures 54 to 57, inclusive. These figures were intended to show the relation of the carbon-hydrogen ratio to the results of the steaming tests.

The carbon-hydrogen ratios of figure 54 were computed from the ultimate analyses of boiler-room samples of coal by the chemical lab-

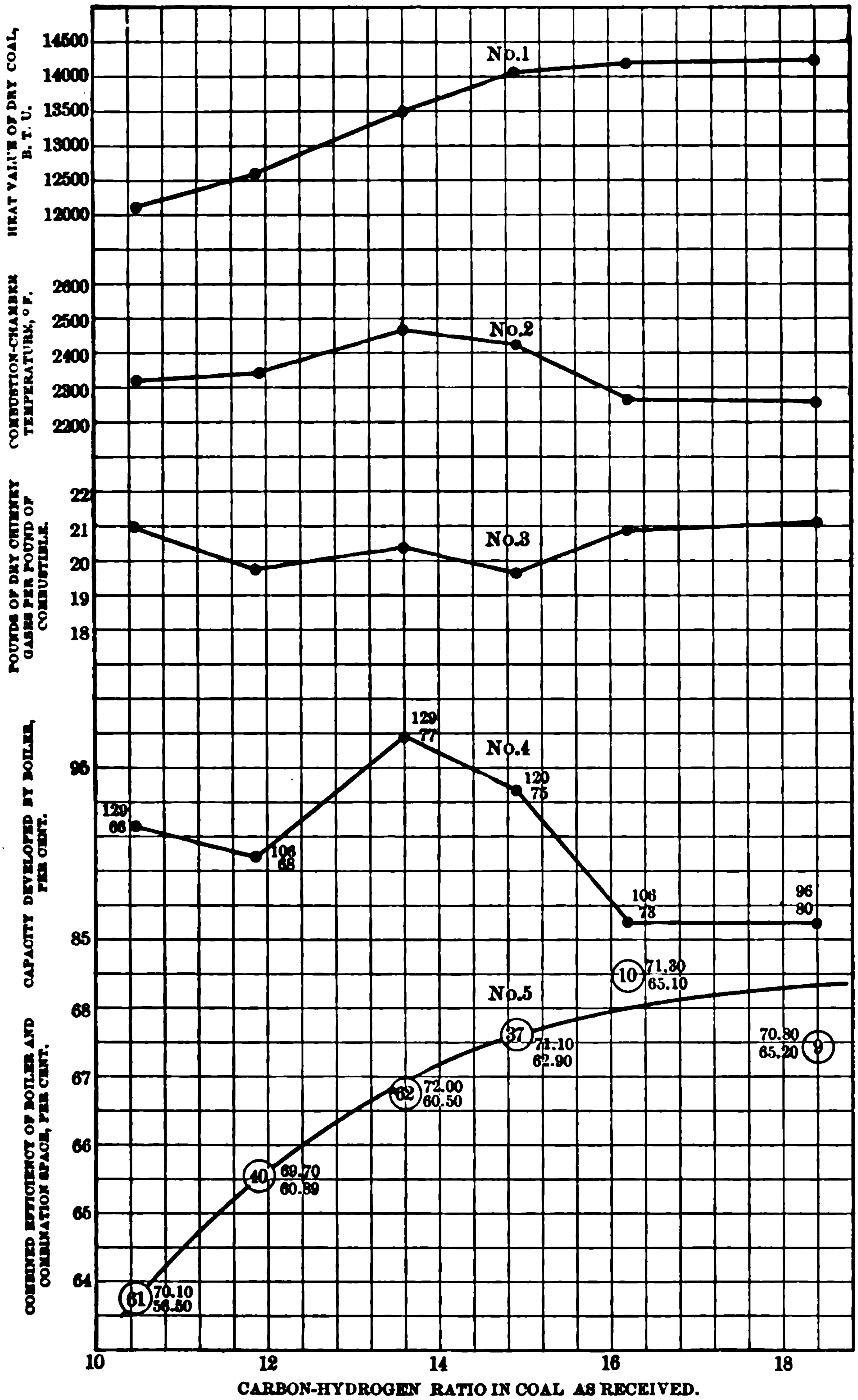


Figure 54.—Curves showing the relation of the carbon-hydrogen ratio of coal as received to: Heat value of dry coal (No. 1); combustion-chamber temperature (No. 2); pounds of dry chimney gases per pound of "combustible" (No. 3); capacity developed by boiler (No. 4); combined efficiency of boiler and combustion space (No. 5).

oratory. These ratios were divided into six groups and several items in each group were averaged and platted.

The two numbers at each point of the capacity curve indicate the highest and the lowest capacity obtained with each group of tests.

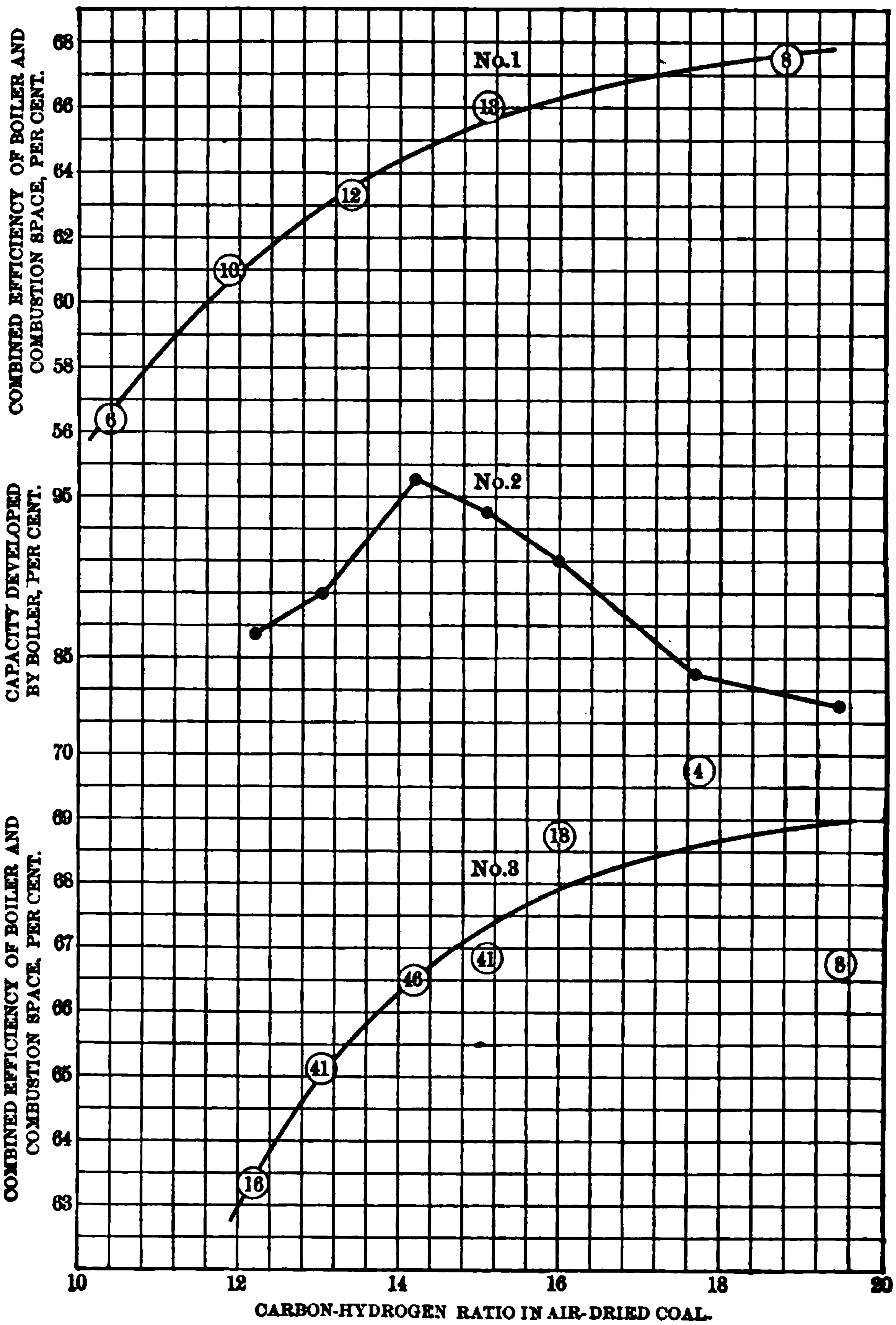


FIGURE 55.—Curves showing the relation of the carbon-hydrogen ratio of air-dried coal to: Combined efficiency of boiler and combustion space (No. 1), tests 1 to 78 run at about the capacity of the boiler; capacity developed by boiler (No. 2), tests 120 to 401; combined efficiency of boiler and combustion space (No. 3), tests 120 to 401, washed and briquetted coals rejected.

As shown in figures 17 and 19, the combined efficiency varies with the capacity. This variation in the capacity of each group of tests accounts, to some extent, for the variation in the combined efficiency indicated by the two numbers at each point.

Curve No. 5 shows that the combined efficiency rises as the carbon-hydrogen ratio becomes larger. According to curve No. 3, the heat loss in the dry chimney gases remains nearly constant, so that the low efficiency at the left of the curve is caused by heat loss in incomplete combustion (*b*) and the heat carried away in the moisture in coal (*c*).

The carbon-hydrogen ratios used in the preparation of figure 55 were computed for air-dried coal from the chemical data from car samples, inasmuch as data from boiler-room samples were not available for the computation. It is true that the moisture in air-dried coal, and, therefore, the carbon-hydrogen ratio, varies with the atmospheric conditions, but the variation is so small that its effect is lost among the combined effects of other factors which are apt to vary over a considerable range.

The data for curve No. 1 were obtained from the first 78 steaming tests. All these tests were run at about the rated capacity of the boiler so that the effect of the capacity is eliminated. The points fall well along a smooth curve.

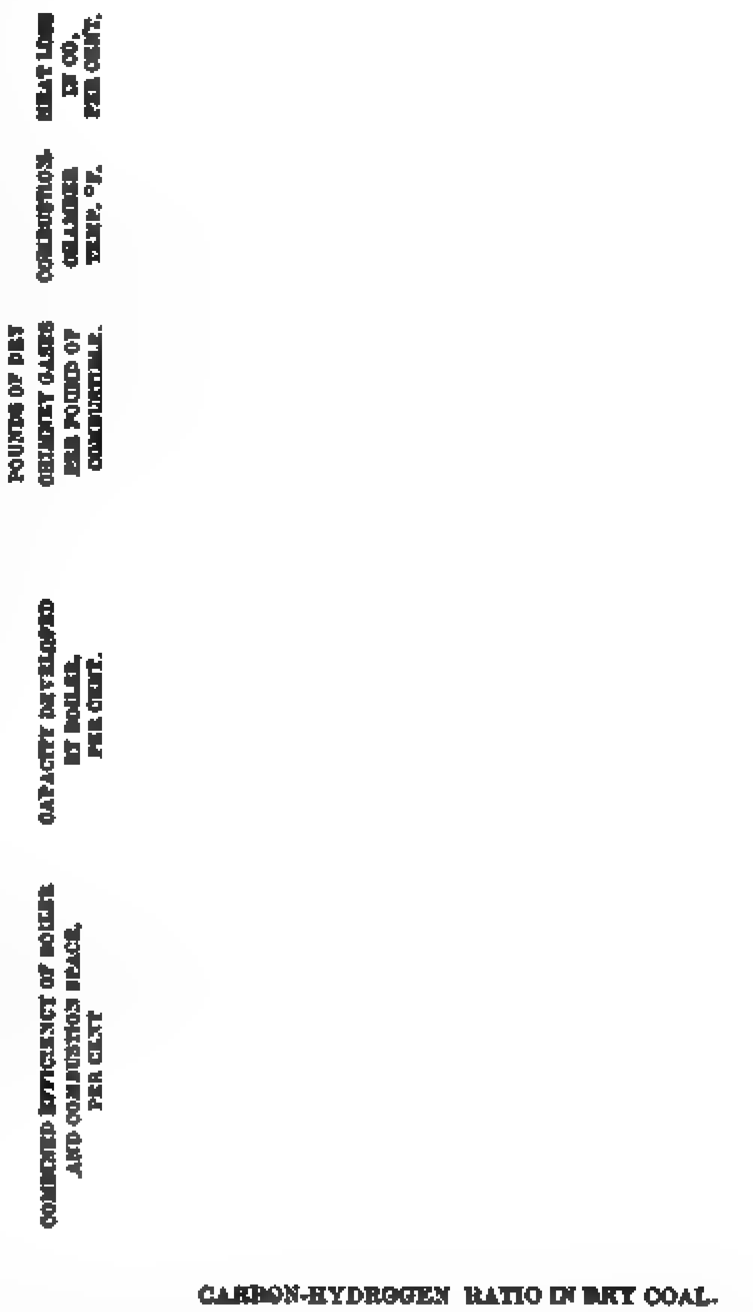


FIGURE 56.—Curves showing the relation of the carbon-hydrogen ratio of dry coal to: Heat loss in CO (No. 1); combustion-chamber temperature (No. 2); pounds of dry chimney gases per pound of "combustible" (No. 3); capacity developed by boiler (No. 4); combined efficiency of boiler and combustion space (No. 5). Tests 120 to 380.

The data for curves Nos. 2 and 3 were obtained from tests 120 to 401, inclusive. The capacity in these tests varied over a considerable range, and the variation accounts to some extent for the fact that the points of curve No. 3 do not fall so well along a smooth curve as those of curve No. 1. Both of the curves, however, show a decided rise in the combined efficiency as the carbon-hydrogen ratio becomes larger.

The carbon-hydrogen ratios used in the preparation of figure 56 were determined from the ultimate analyses of dry coal of boiler-room samples. By figuring the ratio on the basis of dry coal that part

of the hydrogen which forms the free moisture of coal is eliminated. The ratios were divided into seven groups and the averages of each group of the several items of the results of the steaming tests furnished the points shown in the figure.

In general the indication of this figure is the same as that of the last two figures. That is, the combined efficiency rises as the carbon-hydrogen ratio increases.

Curve No. 1 suggests that the low efficiency at the left of the figure is caused more by the incomplete combustion of the volatile combustible than by excessive supply of air; curve No. 3 shows that the latter remains nearly constant.

COMBINED EFFICIENCY OF BOILER AND COMBUSTION SPACE, PER CENT, TESTS 1-78.

COMBINED EFFICIENCY OF BOILER AND COMBUSTION SPACE, PER CENT, TESTS 120-380.

RATIO OF CARBON TO AVAILABLE HYDROGEN.

FIGURE 57.—Curves showing the relation between the ratio of carbon to available hydrogen and the combined efficiency of the boiler and the combustion space. Curve No. 1 includes tests 1 to 78; curve No. 2 includes tests 120 to 380.

Figure 57 gives the relation between the ratio of carbon to available hydrogen and the combined efficiency of the boiler and the combustion space. This ratio does not show such a good relation to the combined efficiency as any of the three ratios previously discussed. The true combustible presents trouble in burning under a steam boiler in so far as it is volatile. The larger part of the difficulties in burning are brought about by the impurities mixed with the coal. Therefore, any such classification as the one under discussion, which is entirely independent of the impurities, is not of any service in determining the value of a coal for steaming purposes.

In figure 58 the tests were grouped on the basis of the ratio of the hydrogen in dry coal to the available hydrogen. The available hydrogen was obtained from the following equation:

$$\text{Available hydrogen} = \text{hydrogen in dry coal} - \frac{\text{oxygen in dry coal}}{8}$$

The ratios used in the figure are those of tests 124 to 380. Washed and briquetted coals were rejected. This ratio increases with the

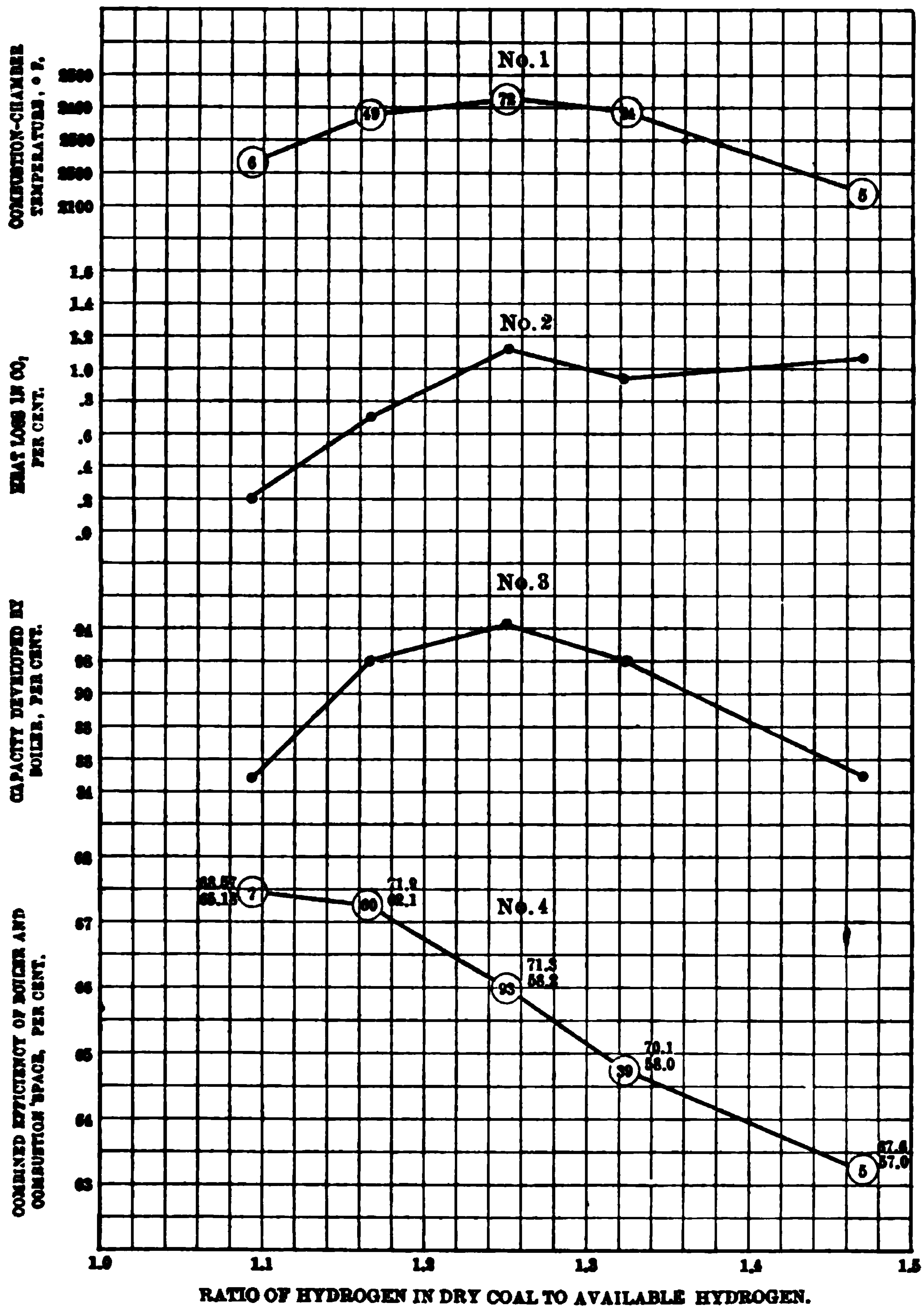


FIGURE 58.—Curves showing the relation between the ratio of hydrogen in dry coal to available hydrogen and: Combustion-chamber temperature (No. 1); heat loss in CO, per cent (No. 2); capacity developed by boiler, per cent (No. 3); combined efficiency of boiler and combustion space, per cent (No. 4). Tests 124 to 380.

volatile combustible in the coal. Therefore, with the high ratios, one would at least expect higher heat losses, due to incomplete combustion of the volatile combustible. Futhermore, the coals high in

volatile matter generally contain high percentages of ash and moisture, so that with high ratios of the hydrogen to available hydrogen there may be incidental loss, due to large supply of air and perhaps additional loss due to the escape of free hydrogen. These heat losses, due to the various causes mentioned, reduce the efficiency of coals having a high ratio of hydrogen to available hydrogen. This fact is borne out by curve No. 4. Curve No. 2 shows a persistent increase in the incomplete combustion as the ratio becomes larger.

Considering the indications of the last four charts, the ratio of carbon to hydrogen in coal as burned seems to be the best of the four ratios discussed for showing the value of coal for steaming purposes.

RELATION OF THE HEAT VALUE OF COAL TO RESULTS OF TESTS.

In figure 59 the grouping of the tests was done on the basis of the B. t. u. per pound of dry coal. The two numbers near each point of curve No. 4 show the highest and the lowest efficiency of each group of tests. Apparently, good efficiency can be sometimes obtained with coals low in heat value, and high-heat-value coals may occasionally show low efficiency. The slope of the curve shows that in general coals low in heat value give low efficiency. This indication, however, is due to the ash and moisture in the coal rather than to the heat value. The good low-ash and low-moisture eastern coals fall to the right of the figure and the lignites and other high-ash and high-moisture coals to the left. The efficiency of the coals low in heat value is reduced by (*a*) high losses in the chimney gases due to large excess of air as shown by curve No. 2, (*b*) less complete combustion due to higher volatile combustible in the coal, higher ash, and higher moisture, and (*c*) higher loss in the moisture in coal.

The impurities in the coals low in heat value besides reducing the efficiency also reduce the capacity of the boiler to a considerable extent; this is shown by curve No. 3.

RELATION OF SIZE OF COAL TO RESULTS OF TESTS.

The size of a coal undoubtedly has an effect on the results that can be obtained with the coal in a given steam-generating apparatus. In general, very fine coal does not give good results under a steam boiler and is undesirable for that purpose. Very large lumps are generally objectionable as steaming fuel for obvious reasons. There is some certain size or combination of certain sizes of each coal that will give the best results in a given furnace. To determine this best size and the effect of decreasing or increasing it, as well as the effect of the various mixtures of the various sizes of the various coals, would be a laborious problem, similar to working a problem of permutation and combination by the ordinary arithmetic method. Such determination would require accurate sizing and mixing and a great many duplicate tests before the exact relation would be determined. The steam-engineering section of the fuel-testing plant could not go into such specialized

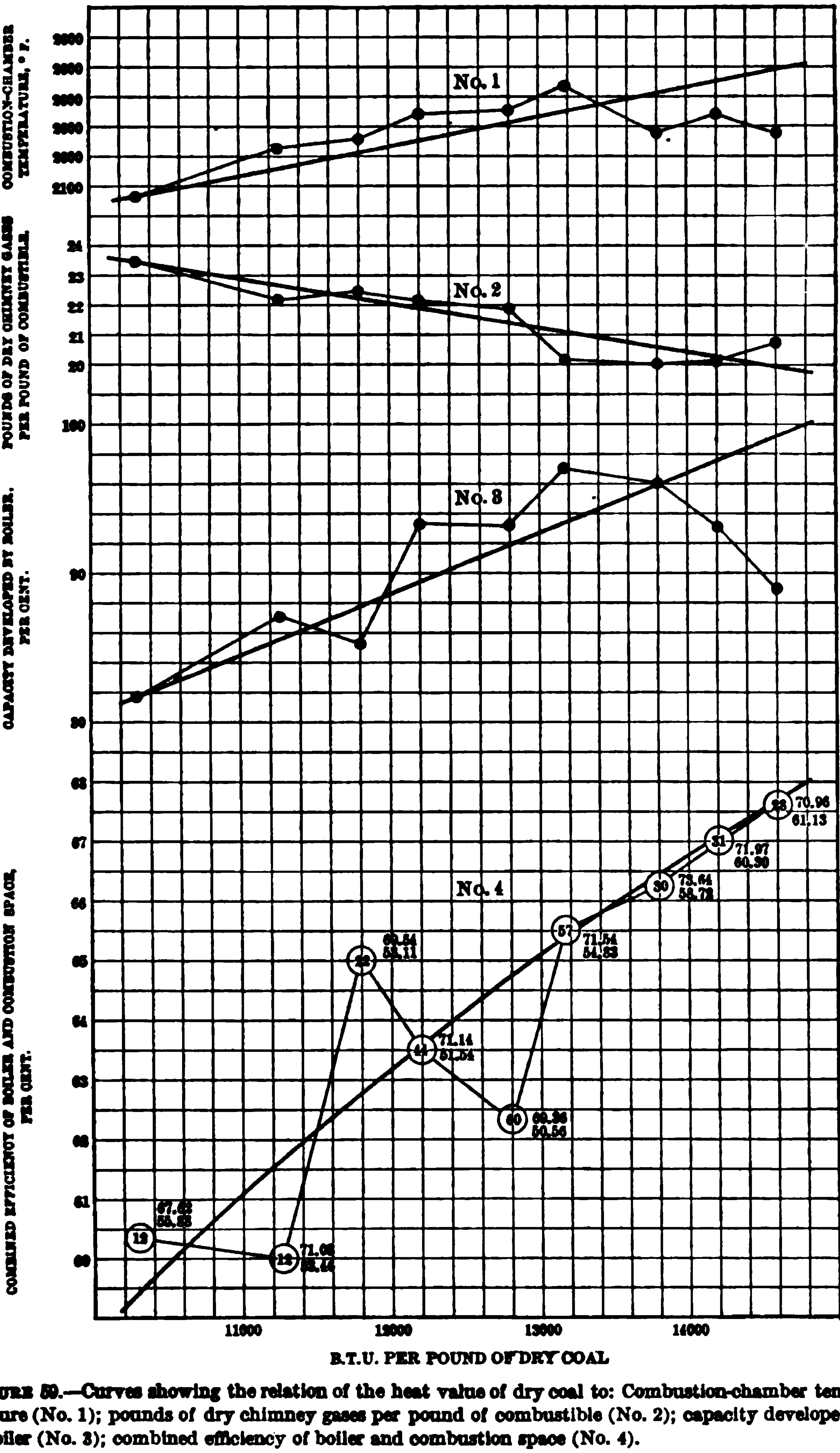


FIGURE 59.—Curves showing the relation of the heat value of dry coal to: Combustion-chamber temperature (No. 1); pounds of dry chimney gases per pound of combustible (No. 2); capacity developed by boiler (No. 3); combined efficiency of boiler and combustion space (No. 4).

lines of investigation. It has, however, done the best it could under the given conditions to shed some light on the question of the best size of coal. Commencing with test 101, the percentages of the various sizes constituting the mixtures in the coals tested have been determined accurately. From the percentages of the mixture the average

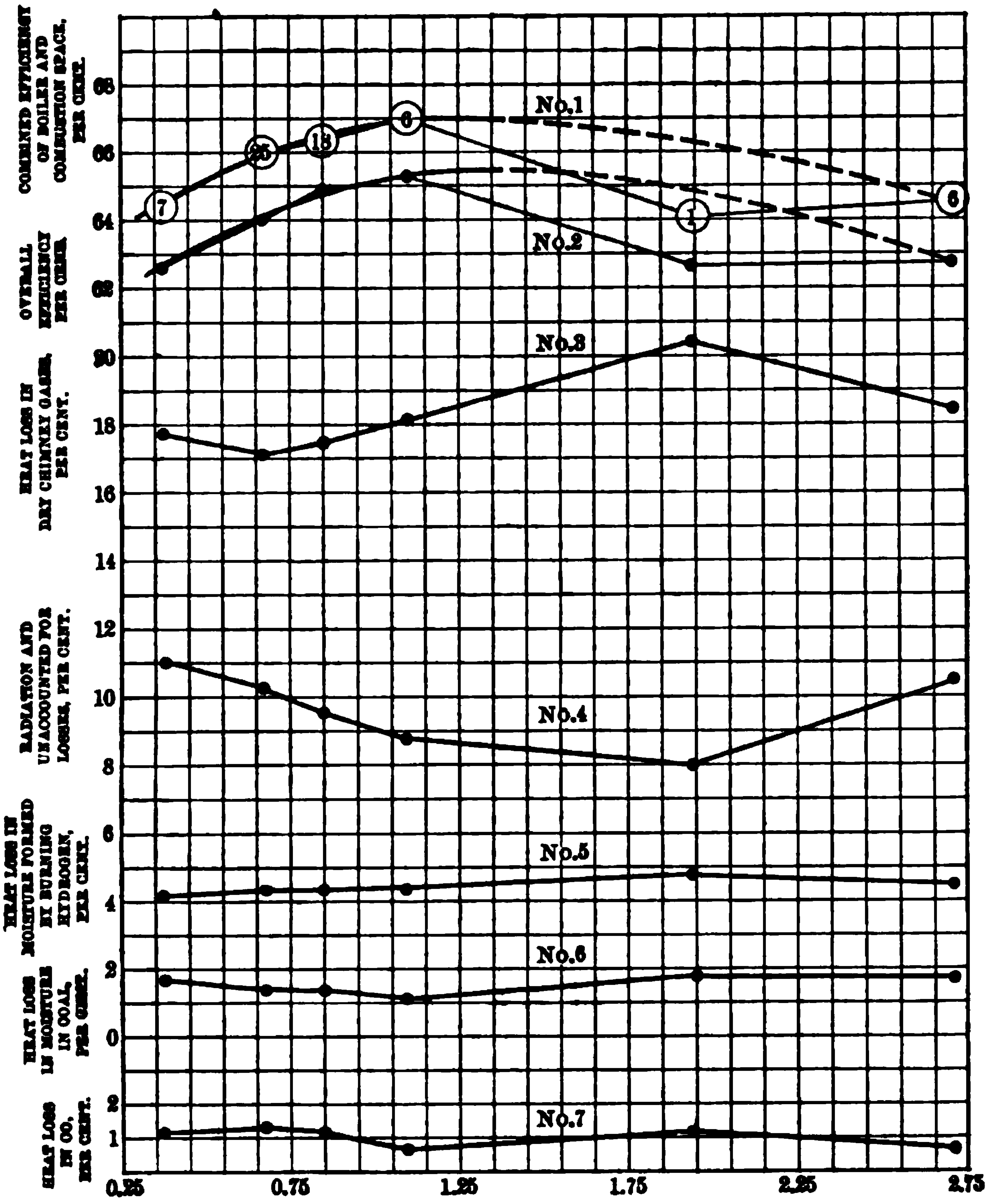


FIGURE 60.—Curves showing the relation of the average diameter of coal to: Combined efficiency of boiler and combustion space (No. 1); over-all efficiency of the steam-generating apparatus (No. 2); heat loss in dry chimney gases (No. 3); radiation and unaccounted-for losses (No. 4); heat loss in moisture formed by burning hydrogen (No. 5); heat lost in moisture of coal (No. 6); heat loss in CO (No. 7). All items of the heat balance are expressed as percentages of the heat of "combustible" ascending from the grate.

diameter was computed as a fictitious value of one size coal. The percentages of the various sizes and the average diameters are given in Table 4. How near or how far this average diameter is equivalent to the one-size coal is a question not easily determined. The reader may try his own scheme of determining the average value of size.

In figures 60 and 61 some of the tests have been grouped on the basis of the average diameter of the coal. The object of preparing

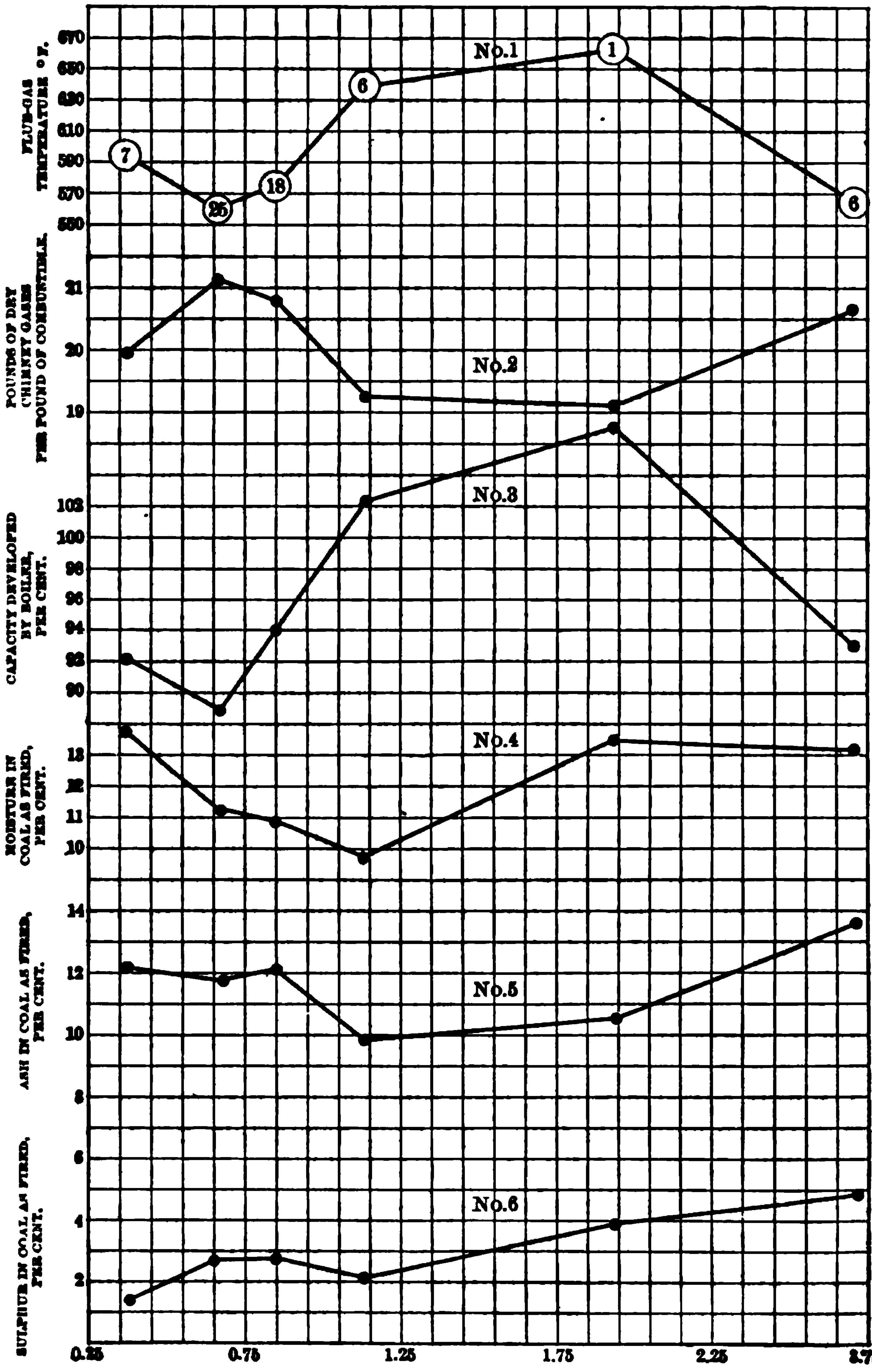


FIGURE 61.—Curves showing the relation of the average diameter of coal to: Flue-gas temperature (No. 1); pounds of dry chimney gases per pound of "combustible" (No. 2); capacity developed by boiler (No. 3); moisture in coal as fired (No. 4); ash in coal as fired (No. 5); sulphur in coal as fired (No. 6).

the two figures was to show the effect of the diameter of the coal on the results of the tests. To eliminate other factors as far as possible

only tests made with Illinois coals were used in the preparation of the two figures.

According to curves Nos. 1 and 2 of figure 60 the best results were obtained with coals having an average diameter between 1 and 1.25 inches. Curves Nos. 4 and 7 suggest that the lower efficiency obtained with the smaller and the larger sizes was due to less complete combustion. The heat loss up the stack, both in dry gases and the combined moisture, remained nearly constant. The less complete combustion was very likely the result of local deficiency of air.

Curve No. 3 of figure 61 shows a considerable rise in the capacity of the boiler as the average diameter of the coal increases from 0.5 to 1.25 inches. However, for very large sizes the capacity drops again. The capacity curve is roughly parallel to the efficiency curve—that is, the two rise and fall together.

Curves Nos. 4, 5, and 6 show to what extent moisture, ash, and sulphur were active causes of the change in the efficiency and the capacity. The drops in the percentages of moisture and ash are quite perceptible up to the point of the highest efficiency; undoubtedly these drops were a factor in the rise of the efficiency.

In the preparation of figure 62 all tests were used, regardless of the nature of the coal, and on that account the indication of the figure is misleading. The good coals of the Pocahontas type crumble easily and in the figure fall to the extreme left, while tough and low-grade coals keep in larger lumps and in the figure fall to the right. The chart shows, therefore, not only the effect of size but also the combined effect of volatile matter, ash, moisture, and sulphur. This is the reason why the smallest coal shows the highest efficiency. Figure 62 is presented merely to show that grouping tests indiscriminately and platting the averages of the groups does not always give reliable indications.

SPECIAL TESTS MADE ON ACCURATELY SIZED BITUMINOUS COALS.

There were seven steaming tests made at the fuel-testing plant with mixed bituminous coals that had been accurately sized previous to testing. The coal of each test consisted of but one size and had been obtained by passing the mixture through a revolving screen having round perforations of various sizes. The coal originally came from several mines located in the Illinois and Missouri coal fields and was accidentally mixed in a general heap in consequence of a fire in the washery plant.

Figure 63 shows some of the many variations encountered when making steaming tests on sized coals. Each of the points in the figure represents a single test made on a single size of coal.

Curves Nos. 1 and 7 indicate that the various sizes were not of the same chemical composition; both the carbon-hydrogen ratio and the ash in the coal are higher in the small-size coal. It is natural that

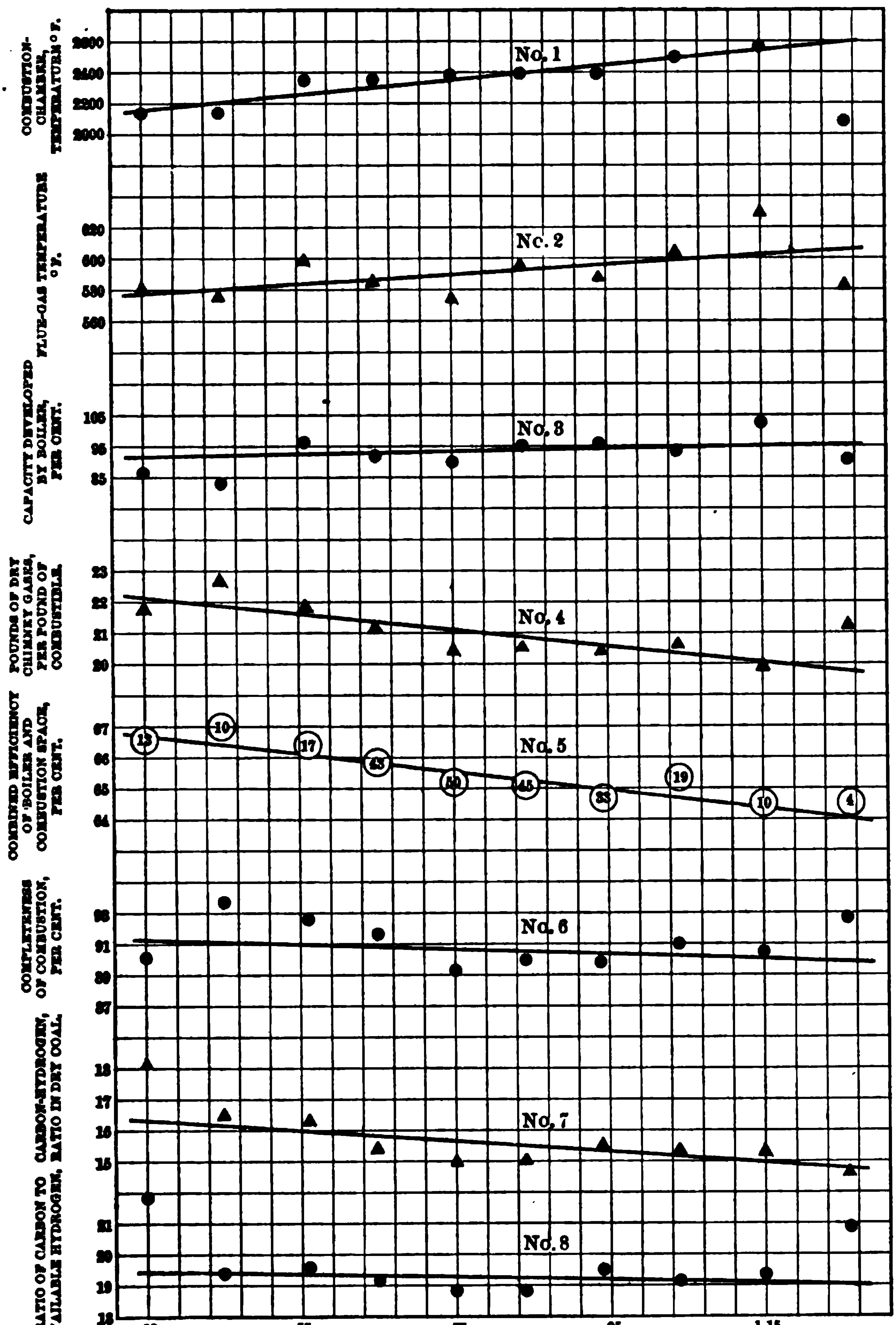


FIGURE 62.—Curves showing the supposed relation of the average diameter of coal to: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); capacity developed by boiler (No. 3); pounds of dry chimney gases per pound of "combustible" (No. 4); combined efficiency of boiler and combustion space (No. 5); completeness of combustion (No. 6); carbon-hydrogen ratio in dry coal (No. 7); ratio of carbon to available hydrogen (No. 8).

small coal should contain more ash than the larger sizes, because the dirt is more friable than the coal itself, and therefore it crumbles easier and finds its way into the small coal.

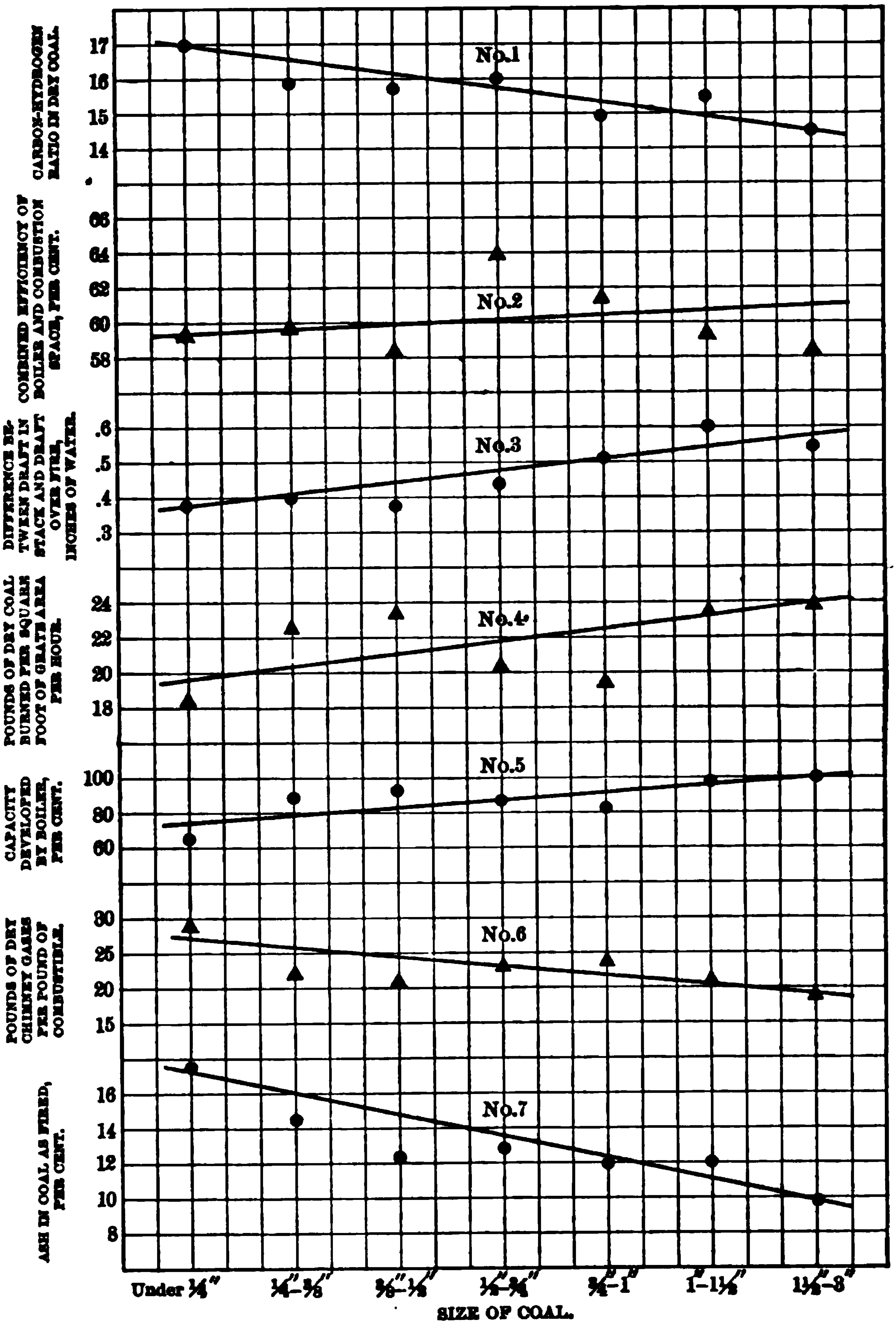


FIGURE 63.—Curves showing the effect of the size of coal on: Carbon-hydrogen ratio in dry coal (No. 1); combined efficiency of boiler and combustion space (No. 2); difference between draft in stack and draft over fire (No. 3); pounds of dry coal burned per square foot of grate area per hour (No. 4); capacity developed by boiler (No. 5); pounds of dry chimney gases per pound of "combustible" (No. 6); ash in coal as fired (No. 7).

The high carbon-hydrogen ratio of the small-size coal can be explained in two ways. Some of the coals constituting the mixture were finer than the others, and it may have happened that this small

coal also had a high carbon-hydrogen ratio, so that the small sizes contained a great deal more of the coal having a high carbon-hydrogen ratio than did the large sizes. Or it may be that the combustible adhering to the slate and other ash constituents has a great deal higher carbon-hydrogen ratio than the rest of the combustible; on this supposition, since the small sizes ran higher in ash, they would also have a higher carbon-hydrogen ratio.

Curve No. 2, giving the combined efficiency of the boiler and the combustion space, is rather irregular, but on the whole it can be said that the efficiency remains about constant as the size of coal increases. However, from the fact that the capacity rises from 70 to 100 per cent (curve No. 5), the efficiency is improved as the size of the coal increases. Figure 23 shows that for a similar rise in capacity with Illinois coal the combined efficiency drops about 3.5 per cent; there is, therefore, at least that much gained with the larger sizes of coals.

Curve No. 6 shows that whatever may be lost in the incomplete combustion due to higher rates of burning the coal, shown by curve No. 4, is perhaps gained by the reduction in the air supply.

These seven tests show that the best results were obtained with coals passing over the ½-inch holes but going through the 1-inch holes in the screen. This best size is somewhat smaller than the best average diameter, as shown in figures 60 and 61. It is a question, however, whether the results of single tests can be trusted.

RELATION OF SMOKE TO THE CHEMICAL COMPOSITION OF COAL AND THE RESULTS OF TESTS.

In figure 64 the tests are grouped on the basis of the percentage of black smoke. The object of preparing the figure was to find the causes of smoke formation and what effect smoke has on the results of the tests.

Smoke is a visible evidence of incomplete combustion. Any factor in the composition of coal which tends to decrease the completeness of combustion is likely to be the cause of smoke. The main cause, so far as the coal is concerned, is a high percentage of volatile matter and the heavy carbon-hydrogen compounds which high volatile matter produces in the boiler furnace. Minor causes of smoke may be ash or sulphur in coal, which may produce a local deficiency of the air supply.

In the operation of the furnace the factors causing smoke may be a high rate of combustion and a general deficiency of air supply, caused by a thick fuel bed.

Curves Nos. 2 and 4 show that incomplete combustion increases with the percentage of black smoke. Curves Nos. 5, 6, and 7 indicate some of the factors in the composition of coal which cause smoke. The presence of oxygen in coal would not perhaps produce smoke, but the oxygen and the volatile combustible in coal rise together, so that it may be said that curve No. 5 suggests high volatile matter as

the cause of smoke. The same cause is suggested by curves Nos. 6 and 7. High volatile coals usually contain a high percentage of ash

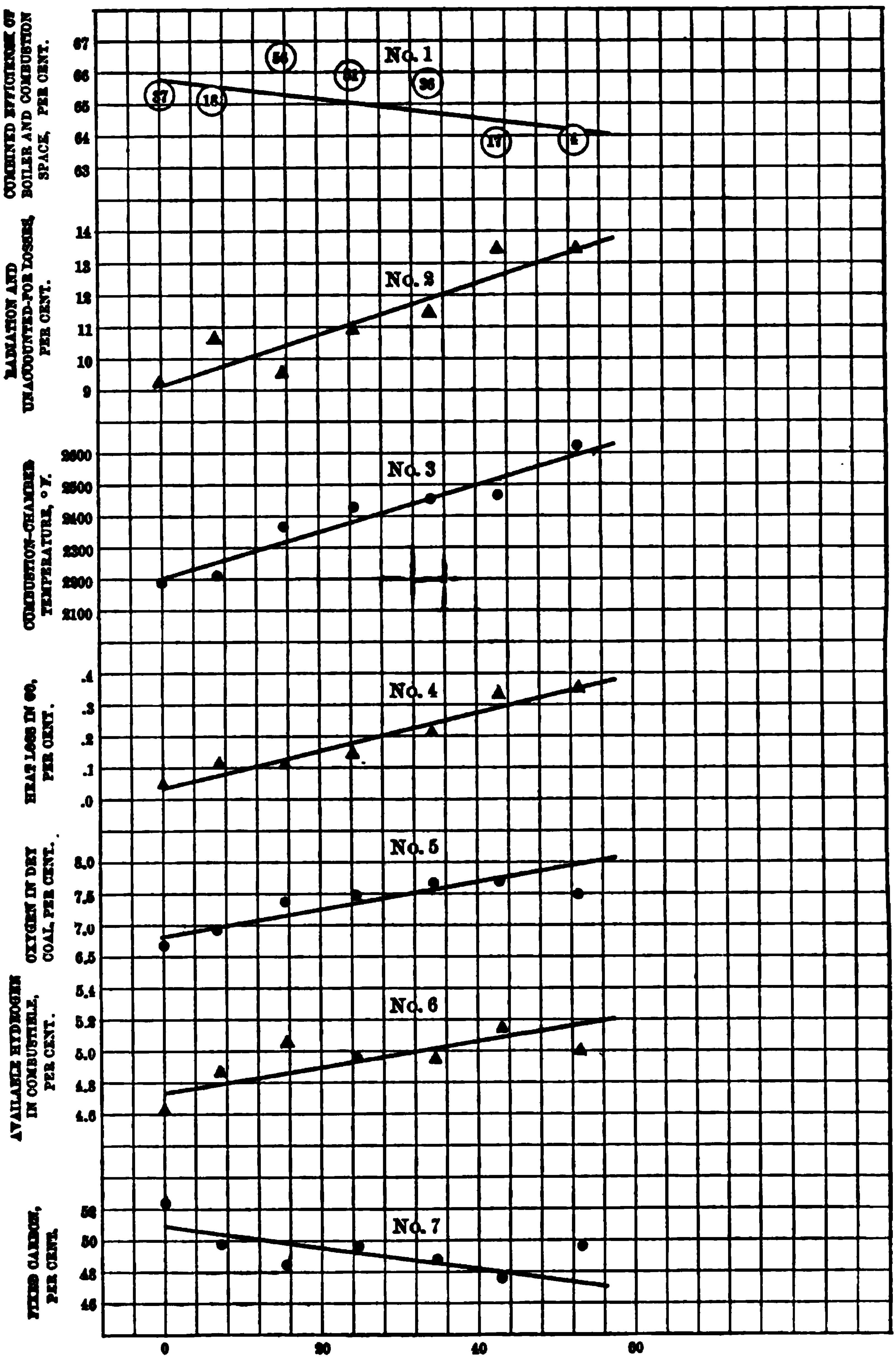


FIGURE 64.—Curves showing the relation of smoke formation to: Combined efficiency of boiler and combustion space (No. 1); radiation and unaccounted-for losses (No. 2); combustion-chamber temperature (No. 3); heat loss in CO (No. 4); oxygen in dry coal (No. 5); available hydrogen in "combustible" (No. 6); fixed carbon (No. 7).

and moisture, so that these last two constituents may also be considered as causes of smoke formation.

SPECIAL OBSERVATIONS IN CONNECTION WITH THE REGULAR STEAMING TESTS.

Besides taking the regular observations during the steaming tests, the steam-engineering division endeavored to carry on as many special investigations in connection with the tests as time and the equipment available for the work permitted. Some of these investigations brought interesting and valuable results, others for various reasons resulted in failure. Those that brought at least partial success are discussed in detail under this heading, and are as follows:

(1) Study of the circulation of water in the tubes of a Heine boiler.

(2) Effect of firing on the temperature at three places in the Heine furnace.

(3) Boiler-furnace gases and their composition at various places in the boiler setting.

(4) Comparison of gas samples obtained with the box sampler recommended by the American Society of Mechanical Engineers, and those obtained with a single perforated tube.

(5) Gas-mixing structures in the combustion chamber.

(6) The effect of a special air-tight boiler setting on the economy.

(7) Comparison of results obtained on boilers Nos. 1 and 2 with those obtained on boilers Nos. 5 and 6.

(8) Measuring the temperature of gases among boiler tubes.

STUDY OF THE CIRCULATION OF WATER IN THE TUBES OF A HEINE BOILER.

The study of the circulation of water in the tubes of a Heine boiler was made by means of a specially constructed instrument called the circulation indicator, which could be placed in any water tube near the rear end. The instrument consisted essentially of a four-blade propeller revolving on a shaft and having attached a small commutator by means of which an electrical circuit was closed once in each revolution of the propeller. An electric battery and a telephone receiver were placed in the circuit. By placing the receiver to his ear an observer could hear a sharp click every time the contact was made on the commutator and thus count the number of revolutions of the propeller.

Figure 65 shows a location of the circulation indicator in the rear of one of the tubes in the third row from the bottom. The details of the instrument and the method of mounting it in the boiler tubes is shown somewhat more in detail in figure 66.

There are seven principal parts which go to make up the instrument, namely, the propeller, the commutator, the brush, which rests on the commutator and makes the contact, the shaft, the supports or bearing of the shaft, the battery, and the receiving instrument,

which may be either a telephone receiver or any suitable recording instrument.

The propeller is made up of four copper blades secured to spokes and set at an angle of 30° with the shaft of the propeller. The spokes are attached to a piece of brass tubing which acts as a hub and also supports a little commutator.

The commutator consists of an insulating glass drum about 1½

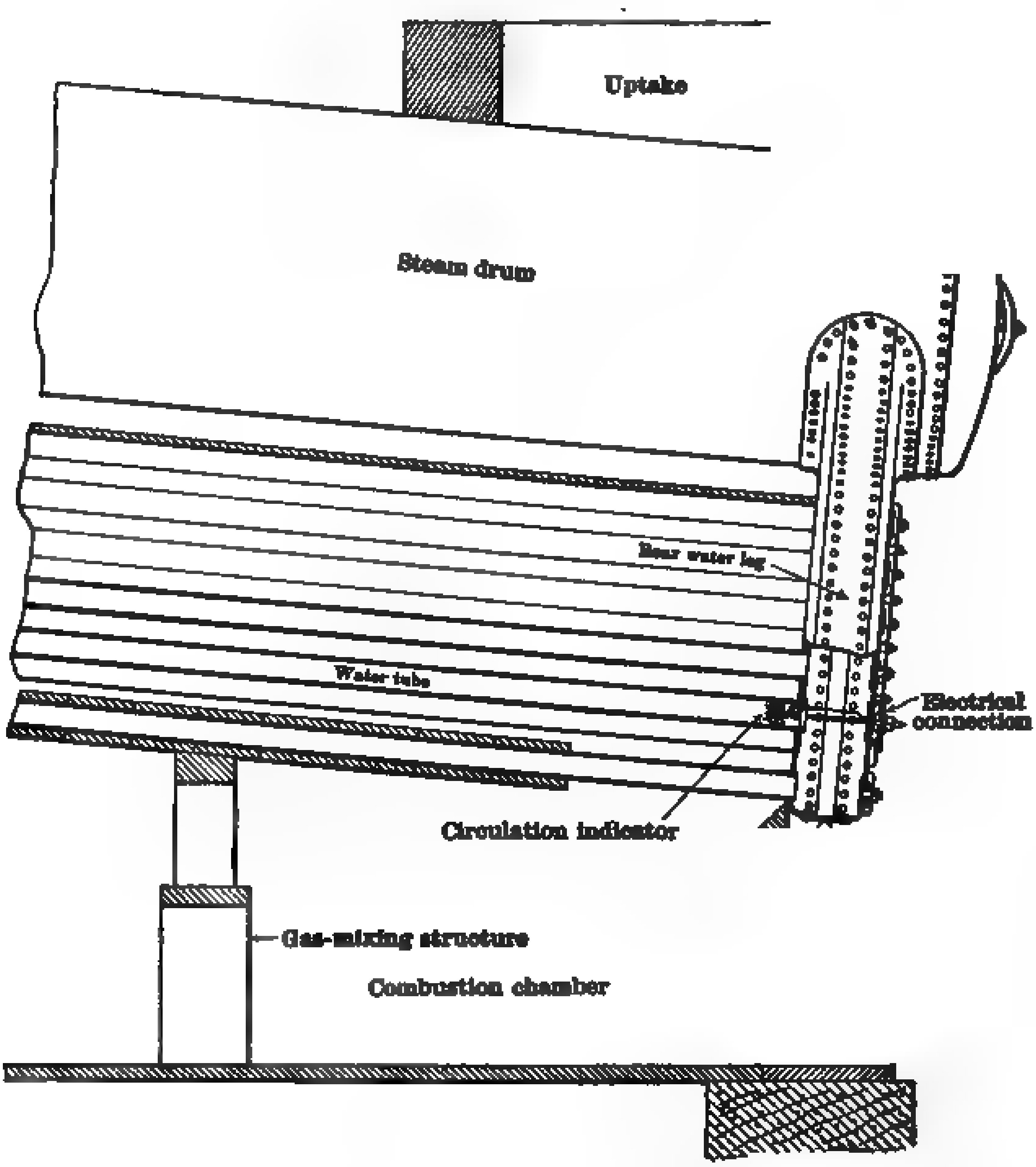


FIGURE 65.—Diagram showing location of circulation indicator in a Heine boiler.

inches long fixed to the hub of the propeller. A strip of copper about ⅛ inch wide and $\frac{1}{32}$ inch thick is bound to the glass drum with copper wire and is electrically connected to the hub and to the shaft of the instrument.

The brush is a piece of watch spring supported on a copper bar that is insulated from the instrument by mica washers. It is arranged at right angles to the contact strip with its free end resting thereupon so as to make and break contact with the copper strip once every

revolution of the propeller. A copper wire which connects to a telephone receiver on the outside of the boiler through a 2-volt battery is fastened to the brush support and is insulated by means of rubber tubing at the point where it passes out of the boiler between the hand-hole cover and the water leg. The other wire from the telephone receiver is grounded to the boiler as shown. By using a low voltage on the line the current is not short-circuited to any extent by the water in the boiler.

The shaft on which the propeller turns is a piece of hard brass wire about ⅛ inch in diameter and about 16 inches long. Two collars attached to the shaft, one on each side of the support, serve to keep

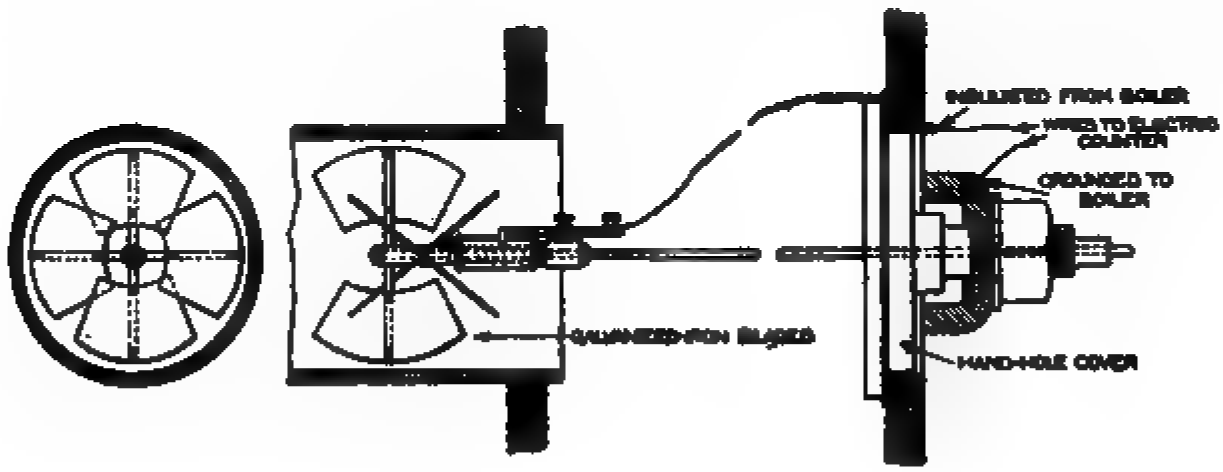


FIGURE 66.—Diagram showing details of circulation indicator and method of mounting it in a boiler tube.

the shaft from moving back and forth. Another collar in conjunction with a cotter pin in the end of the shaft holds the propeller in place.

The support for the shaft, at the end nearest the wheel, is a bar of brass with a hole in the center for the shaft and a slot on each end. These slots, which engage on the outside edge of the boiler tube, as shown, facilitate centering the instrument and changing it from one tube to another. The other support for the shaft was obtained by drilling a hole through the center of a hand-hole cover and fitting the latter with a stuffing box made from the gland of a valve.

In the operation of this instrument the flow of water in any boiler tube into which the circulation indicator may be placed causes the wheel to rotate at a speed proportional to the rate of the flow

of water through the tube. The angle of the blades of the propeller is such that one revolution of the indicator means approximately the passage of 1 linear foot of water. That is, if the propeller makes five revolutions per second, the water passes through the particular tube at the rate of 5 feet per second.

The relation of the revolutions of the propeller to the rate of flow of the water through the tube is similar to the relation existing between the revolutions of the locomotive drivers and the speed of the locomotive. If the drivers are 1 yard in diameter, then with every revolution of the drivers the locomotive moves 3.14 yards. If the drivers are revolving at the rate of five revolutions per second the locomotive moves on at the rate of 5×3.14 yards per second.

The rate of rotation of the circulation indicator in all the trials made has never been too high for an observer to count the clicks; no difficulty was therefore encountered in keeping a record of the rate of flow in any boiler tube under the varying conditions of the operation of the boiler

Several instruments were built and tried before success was attained. At first the propeller was fixed to the shaft and the shaft was made to revolve in the inner support and the stuffing box in the hand-hole cover. With this arrangement the revolutions could be counted by looking directly at the shaft protruding out of the stuffing box. This construction was not found to be quite satisfactory on account of the necessary friction in the stuffing box which retarded the motion of the propeller. It served the purpose only of showing the direction of the circulation. This type of construction was abandoned and the one was adopted with the electrical method of taking observation, previously described.

EFFECT OF CLEANING FIRES AND OF FIRING ON THE WATER CIRCULATION IN THE BOILER TUBES.

Figure 67 shows the effect of cleaning fires, and of firing, on the rate of water circulation in a boiler tube, as measured relatively by the circulation indicator illustrated in figures 65 and 66. The instrument was placed in the rear in the middle tube of the third row from the bottom. The readings were taken by recording the number of revolutions in a 15-second interval and from such data the temporary rate in revolutions per minute was calculated and platted in figure 67.

The circulation varied considerably and was quick in its changes. During the cleaning of the fire it was slow, but as soon as the cleaning was over and the first coal was fired, the circulation increased immediately. Each successive firing increased the circulation toward a normal rate. The curve showing the circulation of water after the cleaning of the fire, is very similar to the curve of the temperature in

TIME.

FIGURE 57.—Curve showing results of observations with circulation indicator. The instrument was placed in the middle tube of the third row from the bottom in the rear of the boiler.

the combustion chamber given in figure 69; that is, the temperature and the water circulation rise and drop together. Undoubtedly the change in temperature in the combustion chamber is the cause of the variation in the water circulation.

RELATION BETWEEN THE CIRCULATION OF WATER AND THE CAPACITY DEVELOPED BY THE BOILER.

Figure 68 has been prepared to show how the circulation of water through the boiler tubes is affected by the capacity. The readings on which this figure is based were taken for several days. The values given in the figure were obtained by counting the total number of

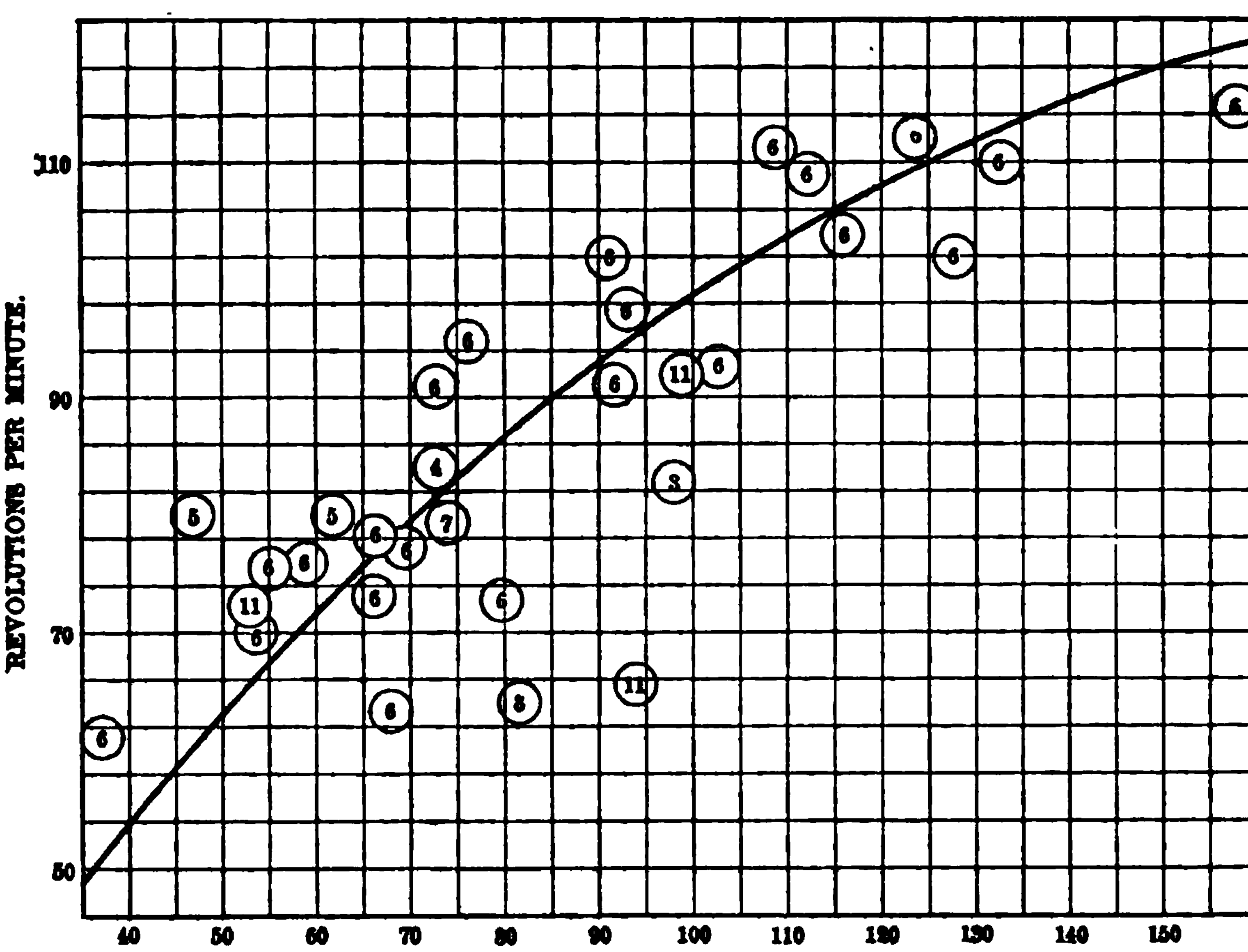


FIGURE 68.—Curve showing the relation between the circulation of water and the capacity developed by the boiler. The circulation indicator was placed in the first tube to the left of center in the second row from the bottom in the rear of the boiler.

revolutions of the circulation indicator for each half-hour period, and by calculating the percentages of the rated horsepower developed by the boiler for each such period. The figures inside of the circles give the number of half hours fulfilling the coordinate values of the points. After platting, the points were averaged in value in both horizontal and vertical strips, each point being included in averaging as many times as indicated by the number in the circle. The vertical and the horizontal averages lie very nearly on the same curve so that only one has been drawn in the figure.

The important indication of figure 68 is that the circulation rapidly drops behind the amount of steam made, especially at high rates

of working. Thus at 70 per cent of rated capacity the average speed of rotation of the indicator was 80 revolutions per minute. At 105 per cent of rated capacity the rate of revolution was 102, whereas to be proportional to the capacity it should have been 120; the speed of circulation fell about 15 per cent short. This lagging in the circulation is reasonable in view of the fact that, so far as one can make any speculations, the circulating forces are perhaps roughly proportional to the amount of steam that is generated and entrained with the rising water, whereas the frictional resistance to circulation is perhaps proportional to the square of the average velocity of circulation. This failure of circulation to keep up proportionally with demands on it must decrease the efficiency of the boiler at higher rates of working, by allowing a proportionally larger percentage of the water-heating surface to be covered with steam bubbles, thus reducing the effectiveness of the heating surface. The result of this condition is less complete absorption of the heat from the gases and a drop in the efficiency of the steam-generating apparatus. That the efficiency does drop is indicated in figures 17, 19, 21, and 23, which should be noted in this connection.

At a later date the circulation indicator was put in the middle tube of the lowest row of tubes, this being one of the tubes inclosed in clay tiles except at the rear end where the gases enter the tube chamber. The revolutions per minute for various capacities are given in the following table:

Speed of circulation indicator for various boiler capacities.

Percentage of rated horsepower developed.	Number of readings.	Revolutions per minute.
58.2	78	217
91.4	8	257
118.2	7	273
92.2	12	291

The number of revolutions at any capacity is approximately three times as great as the number shown in figure 68, for the second row of tubes from the bottom.

In an earlier experiment the same circulation indicator was placed in the third row of tubes from the top of the boiler, and it was found that the rate of revolution was very slow indeed. The receiver would indicate two or three slow revolutions and then 10 to 20 seconds passed without any sign of motion of the instrument. Although the friction of the propeller on its axis was very small, it is possible that the motion of the water was too slow to overcome this friction.

The results obtained with the circulation indicator show that the bottom row of tubes is doing far more work than any other row, and

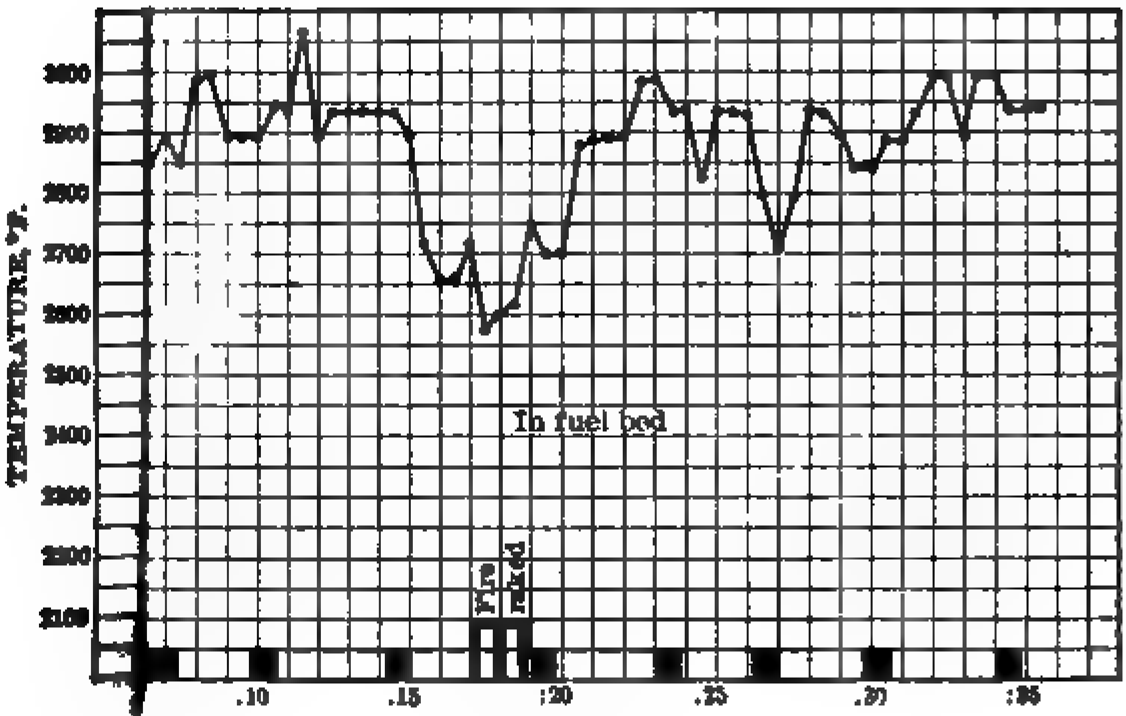
that as we go from the bottom row up the amount of work done by the tubes rapidly decreases.

The fact that the bottom row of tubes absorbs so large a portion of the total heat, which heat is transmitted mostly by conduction through the clay tiles and by radiation to the exposed portion of the tubes in the rear over the hot brickwork, makes it easy to realize that the efficiency of the boiler as a heat absorber may well rise far more rapidly with increasing furnace temperature than is indicated by the equation for heat absorption from the gases due to convection only, as given and explained (on pages 347 to 350) under the heading "Principles involved in heat transmission in steam boilers."

The results of the study of the boiler-water circulation suggest for consideration a feature in the construction of the boilers. This feature which perhaps applies to most horizontal water-tube boilers is the advisability of large water connections between the water tubes and the steam drum, in order that the water may pass through them freely and thus the circulation through the tubes be hindered as little as possible. To make this point clearer let us assume that in the case of the Heine boiler the average velocity of water circulation through all the water tubes is 60 feet per minute at rated capacity, as that figure is not perhaps very far from the actual value. Since the total cross-sectional area of the tubes is 6.7 square feet the tubes will discharge about 6.7 cubic feet of water per second into the front water leg. Now it is plain that if the water passage from the water leg into the steam drum is 2 square feet in area, the velocity of the water through this passage would be over 3 feet per second. This calculation does not take into account the presence of steam which greatly increases the volume of the mixture so that its velocity is perhaps double that figured above and is sufficient to raise the water in the front of the steam drum about 6 inches above the normal water level. If the area of the passage is smaller and the velocity of the mixture high a water fountain may be formed in the front of the steam drum and affect the quality of steam. Or, on account of the increased pressure in the front water leg the circulation in the upper rows of tubes may be reversed, which is perhaps equally undesirable, inasmuch as the steam formed in these tubes always has a tendency to rise and therefore will tend to flow in the direction of the front water leg and thus retard the water circulation. As it is generally admitted that water circulation is essential to good operation of a boiler, all water passages should be made such as to offer as little resistance to the circulation of water as possible.

EFFECT OF FIRING ON THE TEMPERATURE AT THREE PLACES IN THE HEINE FURNACE.

Figure 69 shows the effect of firing two different coals on the temperature at three places in the Heine furnace, namely, in the fuel bed, above the fuel bed, and in the rear of the combustion chamber.



TEMPERATURE, °F.
In fuel bed
Fire raked
.10
.15
.20
.25
.30
.35

The temperatures were measured with the Wanner optical pyrometer. Individual readings of each series of measurements were taken every 30 seconds. Owing to the fact that only one pyrometer was available, the three series of temperature measurement were not taken simultaneously, but one after another, as shown in the figure. The pyrometer was standardized before and after each set of observations. Between the two standardizations the pyrometer was never disconnected from the battery.

The upper three series of temperature readings were taken during a test made with an Ohio coal which was comparatively high in volatile matter. The lower three series were taken during a test with a West Virginia coal low in volatile matter.

The temperature in the fuel bed was taken through an opening about 1½ inches in diameter in the side wall about in the middle of the length of the grate and about 4 or 5 inches above it. In order that the temperature in the fuel bed could be measured, an iron pipe 1¼ inches in diameter was thrust through the opening in the side wall into the hot fuel and again withdrawn, leaving a small tunnel extending 6 to 10 inches into the bed. The temperature of the interior of this tunnel was measured with the pyrometer, looking in through the hole in the wall. Whenever the tunnel caved in it was immediately rebuilt by the application of the iron pipe as mentioned above.

The temperature above the fuel bed was measured through an opening about in the middle of the length of the grate and about 15 inches above it.

The temperature in the rear of the combustion chamber was read through an opening in the side wall about 2 inches in diameter, 2 feet from the inside of the rear wall of the furnace, and about 10 inches below the tubes of the boiler.

Figure 69 shows clearly the following three things:

(1) During and shortly after each firing the temperature over the fire and to some extent the temperature in the fuel bed drops, and the temperature in the combustion chamber rises. The explanation is that the distillation of the volatile matter is a cooling process and is undoubtedly a partial cause of the drop of temperature in the fuel bed and over the fire. Other causes of the drop in the temperature are the evaporation of the moisture in the coal and the inrush of the cold air through the open furnace doors. The volatile matter distilled from the fuel bed is burned in the combustion space, causing a rise in the temperature at the rear of the combustion chamber. As the quantity of volatile matter distilled diminishes the temperature in the fuel bed and particularly over the fire rises and the temperature in the rear of the combustion chamber drops.

(2) The peaks in the curve of the combustion-chamber temperature and the depressions in the curve for the temperature over the fire

are wider for Ohio No. 8, a coal high in volatile matter, than for West Virginia No. 19, a coal low in volatile matter, indicating that the volatile matter is distilled off and burned in a shorter time with the West Virginia coal than with the Ohio coal.

(3) Combustion-chamber temperature is much higher with the Ohio coal than with the West Virginia coal, while fuel-bed and over-fire temperatures are higher with the latter than with the former coal. This contrast indicates that most of the West Virginia coal burns on the grate and only a little in the combustion space, while the opposite is true of the Ohio coal.

In figure 70 is given a comparison of the combustion-chamber temperature taken with the Wanner optical pyrometer and the rise in temperature of water from a water-jacketed gas sampler inserted in the rear of the combustion chamber. A mercury thermometer was inserted into the water outlet of the gas sampler illustrated in figure 73 and was read simultaneously with the optical pyrometer. As the water supply for the gas sampler was about constant the temperature of the water leaving the sampler varied with the temperature in the combustion chamber; thus it was possible to obtain qualitative data on the changes of temperature inside the furnace, which data furnished a partial check on the correctness of the optical pyrometer.

As shown in the figure, the temperature curves of the water from the gas sampler agree very well with the temperature obtained with the optical pyrometer, except that the temperature of the water lags slightly. The elevation of the temperature at A, B, and C in the water temperature curves is due to the reduction of pressure in the water main caused by taking water into the measuring tanks for feeding the boiler. This reduction in water pressure decreased the water supply to the gas sampler, thus causing its temperature to rise. But for this circumstance the curve would run as shown by the dotted lines ADC. The results of these observations show that temperature measurements made with the pyrometer are at least relatively correct.

BOILER-FURNACE GASES AND THEIR COMPOSITION AT VARIOUS PLACES IN THE BOILER SETTING.

GASES LEAVING THE FUEL BED.

When, in the case of hand firing, a fresh charge of bituminous coal is spread over a hot fuel bed, the coal is heated up rapidly and part of the combustible is distilled off shortly after the coal reaches the fuel bed. This distillation is a cooling process and lowers the temperature in the fuel bed and over the fire. The evaporation of the moisture in the coal further lowers the temperature over the fire. The distilled volatile combustible is carried into the combustion space,

where it is more or less completely burned, thereby raising the temperature in the combustion space. That the variation of the temperature is as stated is shown in figures 69 and 70.

The combustible which is distilled from the coal during the first two or three minutes after firing is mostly in the form of gas and tar vapors. Of the two forms, the latter burns with considerable difficulty, and if not consumed in the furnace it is condensed by the cooling action of the boiler to liquid or semiliquid globules of a dark, tarry substance, which forms a part of the black smoke at the top of the stack. The gases burn comparatively easy, and only a small quantity escapes unburned when there is a reasonable amount of combustion space.

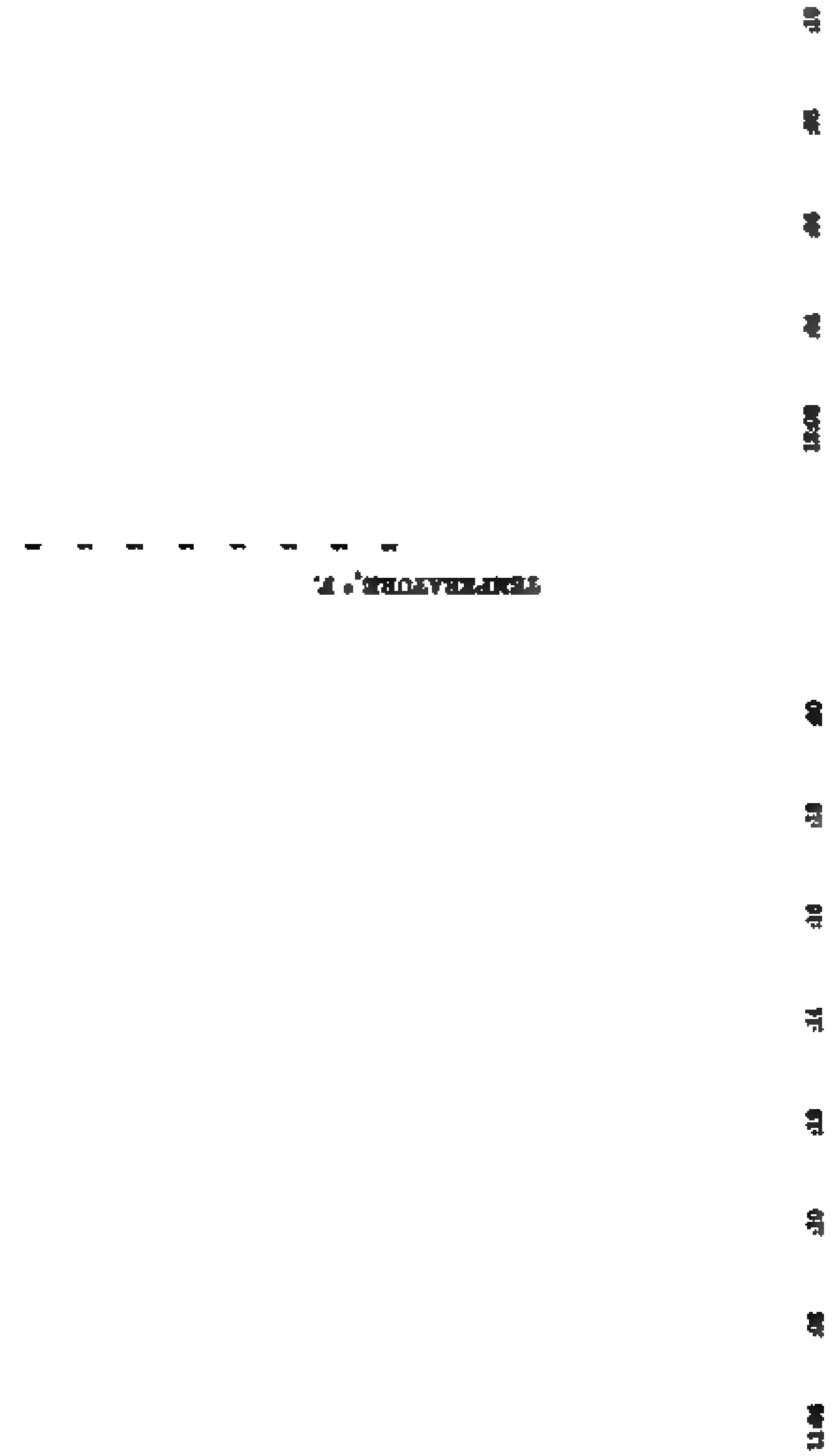


FIGURE 70.—Curves showing the temperatures in the combustion chamber as determined by a Wanner optical pyrometer and by the rise in temperature of the water in a water-jacketed gas sampler.

Table 6 gives the composition of the gases leaving the fuel bed for three minutes immediately after a firing. The gas was collected through a water-jacketed gas sampler, shown in figure 73. The length of time during which each sample was collected was 30 seconds, each sample being held in a separate bottle. The samples were collected and analyzed by Perry Barker, chemist of the steam engineering section.

TABLE 6.—*Analyses of gases leaving fuel bed for three minutes after a firing.*

[Test No. 504. Boiler No. 4. Feb. 4, 1907. Coal, Collinsville, Ill.; nut.]

Time during which sample was taken.	Per cent by volume.						
	CO_2.	O_2.	CO.	C_nH_m.	H_2.	CH_4.	Total combustible.
First half minute	7.6	2.3	18.3	0.2	1.0	1.2	20.7
Second half minute	6.9	1.0	19.8	.3	3.6	1.4	25.1
Third half minute	4.7	.7	20.1	.4	5.5 5.8	2.6 2.5	28.6 28.8
Fourth half minute	4.8	2.2	17.4	.4	4.2 5.0	4.5 4.3	26.5 27.1
Fifth half minute	5.9	1.4	19.1	.2	7.6	3.0	29.9
Sixth half minute	6.6	1.6	15.8	.0	6.8	4.1	26.7

The gases in the column with heading C_nH_m are the illuminant series C_2H_2, C_2H_4, etc.; they were determined by absorption in fuming sulphuric acid. Hydrogen (H_2) and methane (CH_4) were obtained by the explosion method; CO_2, O_2, and CO were determined by absorption in the solutions as used in an Orsat apparatus for the same purpose. The tar vapors, upon entering the water-jacketed gas sampler, were condensed to liquids or solids and could not be determined by a volumetric method.

These analyses show one feature which is worth noting, and that is the percentages of H_2 and CH_4 are low immediately after firing and gradually increase during the three minutes, while the illuminants reach a maximum after about two minutes, and decrease to zero at the end of the third minute. The quantity of the illuminants is somewhat in coincidence with the appearance of smoke, which fact makes it probable that they are partly responsible for the floating carbon forming part of the smoke. Possibly these hydrocarbons are first reduced to carbon and methane before they burn. The carbon thus precipitated from the gases may become incandescent and cause a long, luminous flame.

The percentage of CO remains high during the entire period of three minutes, while that of CO_2 is comparatively low. The high CO is partly the product of distillation of volatile matter and partly the result of decomposition of CO_2. In the lower layer of the fuel bed the carbon burns with oxygen to CO_2, then as the CO_2 passes through the upper layer of hot coke or coal, a molecule of CO_2 takes an addi-

tional atom of carbon and is reduced to two molecules of CO, according to the equation: $CO_2 + C = 2CO$.

The temperature of the fuel bed is so high that although the fuel bed itself may be thin a large percentage of the CO_2 is reduced to CO. This is the process which is employed to gasify fuel in a gas producer. In the latter case the temperature is comparatively low, therefore the fuel bed is generally thick in order that the time of contact of CO_2 with the hot coke may be increased and as much of the CO_2 as possible be decomposed.

That a large part of the CO_2 is decomposed into CO in fuel beds of only such thickness as are used in the boiler furnaces is shown by W. Wielandt's laboratory experiments, described in Gasbeleuchtung, 1900, pages 335 and 574. In these experiments coke was burned in an iron cylinder lined with fire clay and having a cubical capacity of 2.3 liters. Simultaneous gas samples were taken at three different heights above the grate and analyzed; the analyses of the samples have shown the following percentages of CO_2 and CO:

Analyses of gas samples taken at different heights in the fuel bed.

Sample No.	Height above grate (centimeters).	CO_2 (per cent).	CO (per cent).
1	3.5	13.42	9.56
2	9.5	12.80	12.71
3	15.5	11.17	15.42

In these experiments the temperature was about 1,700° C. The results show that CO_2 was formed in the lower part of the bed and was then reduced to CO in the upper part.

In another experiment of Wielandt the air supply was kept constant, but the thickness of bed was varied. The results are shown in the following table:

Analyses of gas samples taken from fuel beds of varying thickness.

Sample No.	Depth of bed (centimeters).	CO_2 (per cent).	O_2 (per cent).	CO (per cent).
1	9.0	12.55	1.17	11.06
2	4.5	18.97	.59	.93
3	1.5	12.29	8.16	.03

The results of this experiment show that as the depth of the bed decreases the percentage of CO falls off and that of CO_2 increases until the maximum CO_2 content is reached. A further decrease in the thickness of the bed increases the percentage of O_2. The thickness of bed giving the best combustion was about 4.5 cm.; a bed of

such small thickness in a steam boiler furnace would be extremely difficult to keep free from holes.

The percentage of CO formed when CO_2 is in contact with hot carbon depends upon the temperature of the carbon and CO_2, and to a certain measure upon the length of time of contact. Up to a certain limit the higher the temperature and the longer the time of contact the greater the percentage of CO formed, although the exact relation is not a direct proportion and varies somewhat with the form of carbon. Figure 72 shows this relation when the carbon is in the form of coke. The figure has been prepared from the results of experiments made by J. K. Clement and L. H. Adams at the University of Illinois, and published in Bulletin No. 30 of that institution. The experiments were made with laboratory apparatus. The coke

FIGURE 71.—Curves showing the effect of the temperature and the time of contact on the percentage of CO formed. Each curve gives the percentage of CO at a constant temperature as indicated. From results of experiments of Clement and Adams, University of Illinois Bulletin No. 30.

was crushed into uniform-sized pieces about 5 mm. in diameter and placed in a porcelain tube of 1.5-cm. inside diameter. This tube filled with the coke was kept at the desired temperature in a specially constructed electric furnace. The temperature inside of the tube was measured with a platinum thermocouple. Carbon dioxide was passed through the tube at a rate which was kept constant during any one single test but which varied with different experiments. The gas leaving the tube was analyzed for CO_2 and CO.

Figure 71 shows that with low temperatures the percentage of CO formed was low, even though the time of contact was long. With higher temperatures—say above 1,200° C. or 2,192° F.—a large percentage of CO was formed in a very short time of contact. Thus, for example, with the temperature at 1,000° C. (1,832° F.), and after the gas had been in contact with the coke 50 seconds, the gas con-

sisted of 62 per cent of CO and 38 per cent of CO_2. But when the temperature in the tube was 1,300° C. (2,372° F.) the gas after a contact of only 4 seconds analyzed 98 per cent of CO and 2 per cent of CO_2.

Inasmuch as the temperature of the fuel bed in a boiler furnace is generally above 2,400° F. (see fig. 69), the gases leaving the fuel bed are apt to be high in CO and low in CO_2, even though the bed may be only a few inches thick. Gas analyses given in Table 7 and the experiments of Clement and Adams show that a boiler furnace is a fairly good gas producer.

In this connection it may be well to give the results of another set of similar experiments made by Clement and Adams at the fuel-testing station of the Bureau of Mines, at Pittsburgh, Pa. The apparatus and the methods of experimenting were the same, but instead of CO_2 superheated steam was passed through the porcelain tube filled with soft-coal coke. The object of this experiment was to determine the effect of temperature and time of contact on the decomposition of steam when in contact with hot carbon. The results are shown in figure 72. According to these results much more steam is decomposed with very short contact when the temperature is above 1,200° C. than with much longer contacts when the temperature is below that point. These results give data on how much of the steam that is sometimes blown under the grate or of the moisture in the coal is decomposed and what the products of decomposition are.

Numerous observations show that the average temperature of the fuel bed in the steam-boiler furnace is about 2400° F. When steam is passed through the fuel bed the length of time the steam is in contact with the hot coal is perhaps from one to two seconds. If the contact lasts one second we find from figure 72 that the resulting mixture of gases contains 28 per cent of steam (the heavy curve No. 6), 36 per cent of CO (the broken heavy curve No. 6), and 35 per cent of H_2 (the light solid curve No. 6). If the time of contact lasts two seconds the resulting mixture will contain only 4 per cent of steam, 50 per cent of CO, and 44 per cent of H_2. The remaining 2 per cent consists of CO_2 and CH_4. If the time of contact lasts four seconds practically all the steam is decomposed. We may then deduce from these curves that, ordinarily, by far the larger part of the steam introduced under the grate is decomposed in the fuel bed, and that if the amount of air supplied over the fire is insufficient this decomposed steam may pass out of the furnace unburned. The fact should be kept in mind that the oxygen of the decomposed steam does not leave the fuel bed in its free state, but that it is combined with carbon, mostly in the form of CO, and, therefore, is not available for the combustion of the free hydrogen. It is possible that the higher incom-

plete combustion losses with coals high in moisture can be accounted for by the partial decomposition of the moisture in coal, and these products of decomposition do not again burn in the combustion space of the furnace.

Figures 71 and 72 suggest the operation of a gas producer at high temperatures, which will not only make the gas much richer, but it will make it possible for the same producer to gasify several times as much fuel as when operated at low temperatures.

The figures also suggest that in a foundry cupola air should be introduced at several places along the vertical column of the coke

H_2O ——— CO ——— H_2 ———

PERCENTAGE OF CONSTITUENTS.

TIME OF CONTACT, SECONDS

FIGURE 72.—Curves showing the main constituents of the gas mixture resulting from passing steam through a bed of hot coke. These constituents are expressed in percentage of total gases consisting of H_2O, CO, H_2, CO_2, and CH_4; the last two are contained in small quantity, varying from 0.5 to 8 per cent. From results of experiments of Clement and Adams, Bureau of Mines Bulletin 7.

and the metal. In the usual way cupolas are now operated the air is introduced only at the bottom of the cupola. The oxygen of the air blast burns to CO_2 within a few inches from the bottom. As the CO_2 passes up through the hot coke above, it is reduced to CO, and as there is no air added above this layer where the reduction takes place, the CO passes out and burns with a hot flame when it comes in contact with air at the top of the stack. Thus a great deal of the fuel used for melting the metal is wasted. At the same time the reduction process of CO_2 cools the upper layers of coke and metal and delays the melting.

The gases leaving the fuel bed are high in combustible not only in the case of the hand-fired furnace, but also when the coal is burned with a mechanical stoker. Table 7 gives the analyses of samples of gases collected near the top of the fuel bed of boiler No. 5 furnace equipped with the Jones underfeed stoker. Column No. 5 gives the distance the end of the gas sampler protruded into the furnace from the inside of the wall. Hole A was in the middle of the length of the grate and about 15 inches above the dead plate. The samples were grab samples and were collected in about one second. They were taken and analyzed by J. C. W. Frazer, chemist of the fuel-testing division.

TABLE 7.—*Analyses of gases leaving fuel bed of boiler No. 5, equipped with Jones underfeed stoker; New River coal.*

Date (1907).	Time of collection.	Temperature (°C.)	Hole from which sample was taken.	Distance into furnace (inches).	Per cent of normal capacity.	Hydrocarbon vapors.	CO_2 (per cent).	Unsaturated hydrocarbons (per cent).	O_2 (per cent).	CO (per cent).	CH_4 (per cent).	H_2 (per cent).	N_2 (per cent).	Total combustible (per cent).
Oct. 15	1.30 p. m.	1,420	A.	10	75	Not determined.	16.2	0.0	2.3	2.1	0.0	0.0	79.4	2.1
Do.	2.00 p. m.	1,350	A.	16	75		5.0	.2	.4	21.9	1.0	3.0	68.5	26.1
Oct. 21	4.00 p. m.	1,450	A.	20	100		5.4	.2	.3	22.3	.54	3.0	68.4	25.94
Do.	4.40 p. m.	1,455	A.	21	100		8.9	.1	.2	15.9	.2	3.0	71.7	16.2
Oct. 23	2.20 p. m.	1,460	A.	6	130		9.9	.2	10.5	.1	......	......	79.3	.3
Do.	3.00 p. m.	1,460	A.	12	125		13.3	.1	1.1	9.3	.0	1.0	75.2	10.4

The analyses show the gases were richest in combustible when the sampling apparatus protruded from 16 to 21 inches into the furnace, or when the ena of the sampler was near the burning heap of coal.

From the gas analyses given in Tables 7 and 8 we can conclude that usually the gases leaving the fuel beds are rich in combustibles and low in free oxygen. The oxygen supplied through the grate is not sufficient for complete combustion of the combustible leaving the fuel bed, and additional air must be supplied through the firing doors or other specially provided openings. Judging from the low percentage of CO_2 leaving the fuel beds, as shown in Tables 7 and 8 (cases in which the sampler was 16 to 21 inches inside the furnace), the fuel bed acts principally as a gas producer; that is, it changes the solid fuel into gas, to which additional air must be added and the mixture burned in the combustion space. These facts prove the importance of spacious combustion spaces in all furnaces burning soft coals.

It should be remembered that Tables 7 and 8 give only the analyses of the gaseous constituents of the combustible leaving the fuel bed. A considerable quantity of the combustible leaves the fuel bed in the form of tar vapors which condense in the water-jacketed gas samplers and are not included in the analyses herein discussed.

BURNING OF GASES AS THEY PASS THROUGH THE COMBUSTION SPACE.

It has been pointed out in the preceding discussion that the gases leaving the fuel bed are rich in combustibles and deficient in free oxygen. For this reason some provision to supply air above the fuel bed is made in most of the commercial appliances designed to burn soft coal. The importance of the gas-mixing devices and of the combustion space has also been realized. Furnaces designed to burn soft coal generally have large combustion space; the gas-mixing structures, however, are still in the experimental stage, their chief drawback being lack of durability under the high temperatures which good fuel economy requires. The gas analyses given in Table 8 show the effectiveness of the combustion space in the Heine furnace.

TABLE 8.—*Analyses of gas samples collected at the top of fuel bed and rear of combustion chamber.*

	Time.	CO_2 (per cent).	O_2 (per cent).	CO (per cent).	H_2 (per cent).	CH_4 (per cent).	C_nH_m (per cent).
Test 364:							
Top of fuel bed	12.30	5.7	0.0	20.3	6.0	2.7	0.0
Rear of combustion chamber	12.30	12.6	5.6	.0	...	...	...
Test 367:							
Top of fuel bed	7.30	4.4	7.4	9.5	1.2	2.4	.8
	9.30	5.4	.0	23.6	7.8	1.2	.2
	11.30	5.2	.2	23.8	5.4	1.8	.0
Rear of combustion chamber	7.30	13.3	.0	.9	...	...	...
	9.30	15.5	.6	.7	...	...	...
	11.30	14.6	.2	1.0	...	...	...

The table gives the analyses of two sets of samples, one collected at the top of the fuel bed and the other in the rear of the combustion chamber. The samples were taken simultaneously at the two places mentioned and the duration of collecting each two was 10 minutes. The gases were drawn from the furnace through the water-jacketed samplers shown in figure 73, A. The samplers projected about 10 inches into the furnace, both being inserted through holes in the side wall, the first sampler resting on the surface of the fuel bed. At the time these samples were collected there was no gas-mixing device in the furnace.

As shown by the analyses, the combustible gas is nearly completely burned by the time the gases reach the rear of the combustion chamber. This much can be said about the gases, but when we look into the furnace near the end of its combustion space very often we can see smoky fluid leaving the furnace. This smoky fluid undoubtedly consists of unconsumed tar vapors and very small particles of solid carbon. These two last combustible ingredients need very much more time for their complete combustion than do the gases. It is not difficult to burn the gases; it is the tar vapors and the solid small particles of floating carbon which present the difficulty in the combustion of soft coals.

INFILTRATION OF AIR INTO THE BOILER SETTING.

The air entering the furnace through the small openings and cracks in the firing doors is useful, and is to a great extent necessary for the complete combustion of the gases and tar vapors leaving the fuel bed; in fact, air entering the furnace through any opening in the walls may be of some benefit for the combustion of the fuel, and therefore need not be always regarded as harmful. But the air entering the boiler setting beyond the furnace where no combustion is taking place is always detrimental to good economy inasmuch as it lowers the temperature of the products of combustion thus making less heat available for absorption by the boiler. All brick boiler settings are more or less leaky, and, even if well cared for and the cracks constantly patched, there will be a considerable air leakage into the boiler setting.

At the fuel-testing plant at St. Louis, Mo., a man was almost constantly employed to patch up the leaks in the settings of the boilers, nevertheless considerable leakage was shown by the analyses of the flue-gas samples collected at different places. Table 9 gives the analyses of two sets of gas samples, one collected in the rear of the combustion chamber and the other at the base of the stack. Those collected at the rear of the combustion chamber were drawn through the water-jacketed gas sampler; those taken at the base of the stack were drawn through the single-tube sampler described on page 32. The collection period of each sample was 30 minutes; the two samples, one at each place, were taken simultaneously. The object of taking these gas samples was to determine the leakage of air between the place where the gases leave the combustion chamber and the place where they leave the setting.

TABLE 9.—*Analyses of samples collected simultaneously at the rear of the combustion chamber and at the base of the stack.*

Place.	Time.	CO_2 (per cent).	O_2 (per cent).	CO (per cent).	CH_4 (per cent).	Sum (per cent).
Rear of chamber	9.00	13.4	4.6	....	....	18.0
	9.30	15.0	3.6	0	0.4	19.0
	10.30	14.4	3.1	0	.0	17.5
	12.30	15.4	1.8	0	....	17.2
	1.30	14.6	3.2	0	....	17.8
Average	....	14.5	3.3	0	....	17.8
Base of stack	9.00	10.0	9.2	0	....	19.2
	9.30	11.0	7.8	0	....	18.8
	10.30	11.2	7.6	0	....	18.8
	12.30	11.0	7.9	0	....	18.9
	1.30	10.5	7.9	0	....	18.4
Average	....	10.7	8.1	0	....	18.8

The weights of gases per pound of carbon figured from the analyses of the gas samples taken at the two places were 17.5 and 23.2 pounds respectively. These weights indicate that of the air supply shown by the gas composition at the base of the stack about 26 per cent leaked in after the gases left the furnace. This large air leakage makes it imperative that if the information obtained from the gas analyses is to be of any value in controlling the fire, the gas samples should be collected at some place before they are diluted by leakage

AMOUNT OF AIR ENTERING THE BOILER SETTING AT DIFFERENT PLACES.

From the gas analyses given in Tables 8 and 9 it is possible to compute the weight of gases per pound of carbon at the three places where the gas samples were taken. From these computed weights can be approximately determined the percentages of air entering the boiler setting between these three points. Table 10 gives these computed values in a condensed form. In the first part of the table are the average analyses of the gases at the three places as given in Tables 8 and 9. The second part of the table gives the weight of the gases per pound of carbon as computed by the general formula:

$$\frac{44\times CO_2+32\times O_2+28\times(CO+N_2)+2\,H_2+16\times CH_4+28\,C_nH_m}{12\,(CO_2+CO+CH_4+2\,C_nH_m)}$$

In this formula it is assumed that C_nH_m is all ethylene, C_2H_4.

The third part of the table gives the weight of air supplied at the various places; the first column gives it in pounds and the second in percentage of the air as indicated by the analyses of gases collected at the base of the stack. As the figures indicate, most of the air is admitted through the firing door in front of the furnace. This air enters when the doors are open during the firing and through the special air openings provided with the Hughes smoke preventer after each firing.

The air that enters the setting between the rear of the combustion chamber and the base of the stack leaks in through the cracks in the side walls, around the two water legs, the steam drum and the walls, around the plugs in the stay-bolt holes, through the brick top of the boiler setting, which is usually thin, around the drop door on top of the boiler, and through many other apparently insignificant small openings. The sum of all these small leaks is a large figure which forms a considerable percentage of the total air admitted into the setting.

TABLE 10.—*Average composition and weight of gases and average weight of air admitted.*

1. AVERAGE COMPOSITION OF GASES.

[Percentage by volume.]

Point of sampling.	CO_2.	O_2.	CO.	H_2.	CH_4.	C_nH_m.	N_2.
Top of fuel bed	5.2	1.9	19.3	5.1	2.02	2	66.3
Rear of combustion chamber	14.0	1.6	0.6				83.8
	14.5	3.3	.0				82.7
Base of stack	10.7	8.1	.0				81.2

2. AVERAGE WEIGHT OF GASES PER POUND OF CARBON.

Point of sampling.	Pounds.
Top of fuel bed	8.4
Rear of combustion chamber	17.2
Base of stack	23.2

3. AVERAGE WEIGHT OF AIR ADMITTED PER POUND OF CARBON.

Point of sampling.	Pounds.	Per cent.
Under grate	7.4	33.3
Into furnace	9.1	41.0
Into setting beyond combustion chamber	5.7	25.7
Total	22.2	100.0

In this connection the authors again state that the settings of the test boilers at the Government fuel-testing plant at St. Louis were well cared for. All the walls were painted two or three times with thick barn paint and a man spent daily four or five hours in patching the cracks or otherwise reducing the infiltration of air, so that the leakage shown in the preceding discussion is perhaps smaller than that in the average steam plant.

VARIABLE AIR LEAKAGE.

The amount of air leaking into a boiler setting has significance only when compared with the air entering the furnace through the grate or firing door—that is, when expressed as a percentage of the total air used or of the air fed in through the grate. Thus, the same weights of air leaking into the setting in a given time may show different excesses over the most economical air supply. The same difference between the gas pressures inside the setting and the outside atmosphere causes the same weight of air to leak into a given setting. However, if in one case the coal burns freely and no clinker is formed on the grate and if the fuel bed itself is thin, the air finds very little resistance in flowing through the grate and the fuel bed. Consequently a large quantity of air enters the furnace through the fuel bed and is utilized in gasifying a larger quantity of coal. This increased quantity of gaseous combustible requires also a larger air

supply through the firing doors. Thus, in such a case, the weight of the air supplied through the fuel bed and through the firing doors is large. In another case the coal may be very fine and may have very fusible ash which forms solid clinker on the grate. The coal may cake badly so that the whole fuel bed may be one mass of fused fuel. In addition to this, the fuel bed may be very thick. All these circumstances will greatly increase the resistance of the fuel bed to the flow of air, so that with the same draft as in the previously considered case much less air finds its way into the furnace through the fuel bed, and therefore much less of the coal will be gasified. A smaller quantity of the combustible gases will also require a smaller air supply through the firing doors, so that the quantity of air entering through the fuel bed and through the firing doors is much smaller in this second case than in the first one. However, since the difference between the gas pressure inside the setting and the outside atmosphere is about the same in both cases, the leakage in the second case will be much larger in proportion to the total air admitted into the boiler setting than it was in the first case. Thus it is apparent that the percentage of leakage in different tests will be different, and will vary with the properties of the coal and its ash and also with the methods of burning the coal.

Table 11 gives the weight of dry gases per pound of carbon, calculated from analyses of gas samples taken simultaneously at different parts of the boiler setting. As shown by the last column, the leakage varies over a considerable range.

The reader should bear in mind that all the data on the composition of the gas leaving the fuel bed and of the gas in the rear of combustion chamber, as well as the deductions drawn from these analyses, are reliable only as far as the gas sample collected through the water-jacketed sampler can be trusted to represent approximately the average gas at the respective places.

TABLE 11.—*Infiltration of air through setting.*

Test No.	Pounds of gas per pound of carbon.				Leakage between combustion chamber and stack (per cent).
	Over fire.	In combustion chamber.	At front water leg.	In stack.	
318	....	18.38	19.20	23.34	21.3
319	....	24.02	27.89	32.42	25.9
320	....	23.76	25.31	28.37	16.2
321	....	16.85	19.64	23.20	27.4
323	....	16.17	17.88	21.60	25.1
324	....	19.93	23.75	26.51	24.8
325	....	19.44	22.40	27.30	28.8
326	....	20.38	23.83	31.45	35.2
327	....	23.21	25.50	28.87	19.6
328	....	17.96	21.00	24.42	26.5
329	....	....	23.38	26.90	....
330	....	....	21.51	25.09	....
332	....	....	18.62	23.60	....
334	....	....	21.09	24.26	....
344	....	21.70	....	27.85	22.1

TABLE 11.—*Infiltration of air through setting*—Continued.

Test No.	Pounds of gas per pound of carbon.				Leakage between combustion chamber and stack (per cent).
	Over fire.	In combustion chamber.	At front water leg.	In stack.	
347	10.22	19.40	....	26.80	27.6
348	12.12	17.53	....	24.52	28.1
349	7.77	14.76	....	20.86	29.2
349	11.15	15.78	....	....	....
350	10.54	16.31	....	23.41	30.3
351	12.73	22.91	24.25	30.25	24.3
352	....	20.51	26.87	27.21	24.6
353	15.17	22.15	....	25.57	13.4
354	....	25.27	27.83	32.00	21.0
355	15.29	20.90	25.42	26.78	22.0
356	18.22	19.84	22.50	25.28	21.5
357	13.65	20.68	....	29.12	29.0
359	....	21.88	....	26.78	18.3
360	....	20.50	....	25.16	18.5
361	....	19.04	....	25.49	25.3
362	13.27	22.48	....	29.70	24.3
363	....	21.81	....	27.17	19.7
364	12.45	19.15	....	25.30	24.3
365	....	21.10	....	29.18	27.7
366	....	22.29	....	26.02	14.3
367	11.77	18.44	....	26.40	30.1
369	....	21.89	....	27.73	21.1
370	....	22.22	....	27.78	20.0
371	....	30.90	....	37.05	16.6
372	....	19.14	....	24.54	22.0
375	....	20.02	....	26.48	24.4
376	....	22.48	....	30.05	25.2
377	....	26.26	....	34.48	23.9
378	....	30.48	....	32.05	4.9
379	....	25.02	....	27.72	9.8
380	....	25.80	....	30.70	16.0
381	....	28.21	....	32.20	12.4

Average percentage increase from surface of fire to combustion chamber, 34.4; from combustion chamber to front leg, 11.9; from front leg to stack, 14.1; from combustion chamber to stack, 22.4.

WATER-JACKETED GAS SAMPLERS.

The construction of the water-jacketed gas sampler that was used to collect gases from the top of the fuel bed and from the rear of the combustion chamber is shown in figure 73, A. The sampler consists of a 1¼-inch pipe closed at each end with a cap, and two ¼-inch pipes. The gas is drawn through one of the ¼-inch pipes, which passes through both of the caps as indicated in the figure. The other ¼-inch pipe brings cold water into the large pipe; a ¼-inch nipple is fitted into the latter and serves as a water outlet. Any steady water supply can be used to furnish the cooling water.

The samplers B and C, figure 73, are of more recent construction. The outside pipe is a standard ¾-inch pipe; the tubes on the inside are of drawn copper. The sampler B has a single tube for gas, ¼ inch in outside diameter; this tube is placed within another copper tube of ½-inch outside diameter. The cooling water is brought in through the ½-inch tube and returns through the ¾-inch outside pipe and leaves the sampler through the attached ¼-inch nipple. The joint at the end of the sampler extending into the furnace is brazed; the joint at the other end is soldered.

The sampler C has three ¼-inch copper tubes for drawing gas; one of these is placed within the ½-inch water-supply tube and runs the full length of the sampler. The second tube for drawing gas comes out through the side of the sampler 11 inches from the end; and the third gas tube comes through the side 22 inches from the

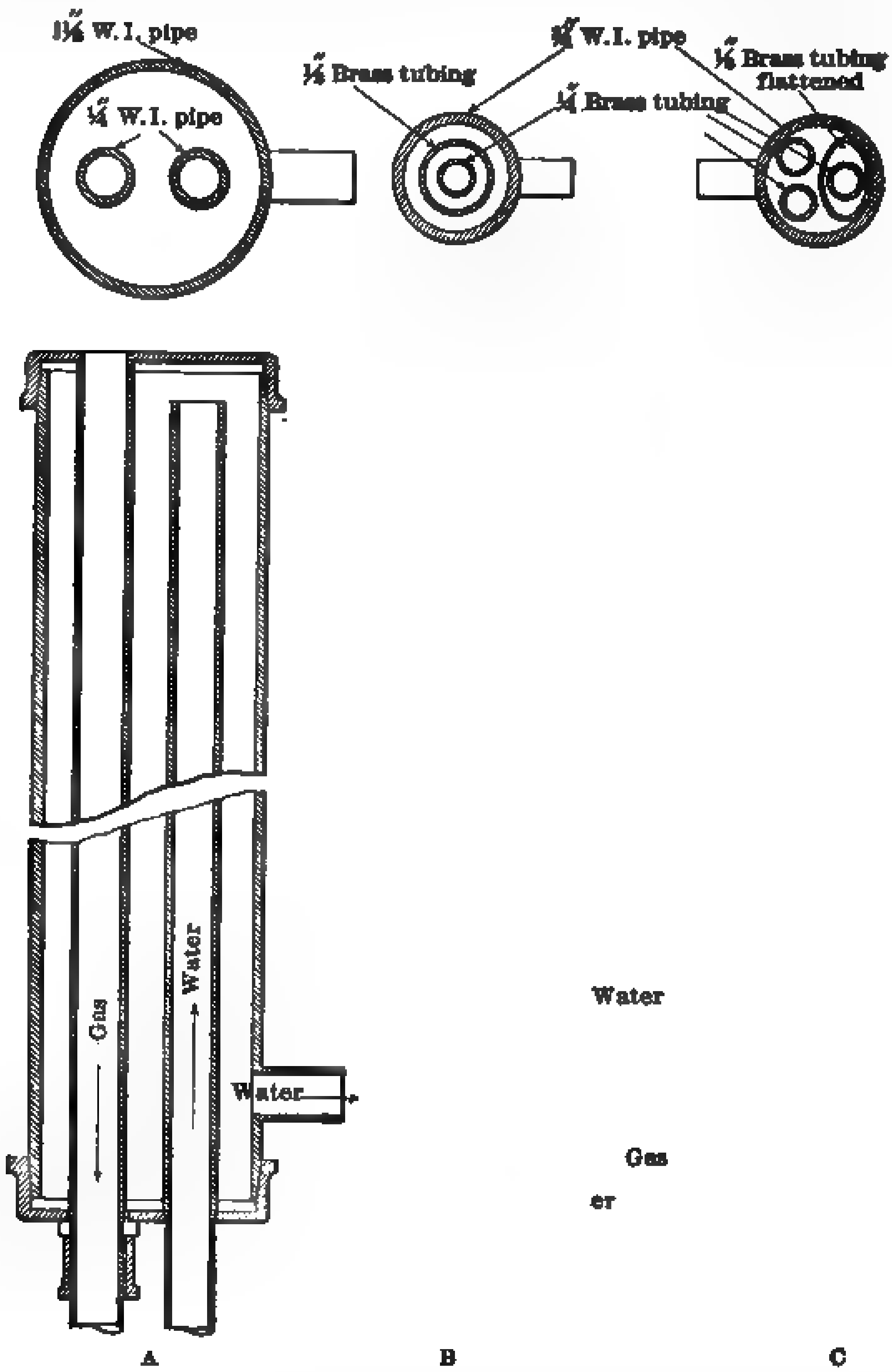


FIGURE 73.—Diagram showing construction of water-jacketed gas samplers.

end of the sampler, or 11 inches from the end of the second gas-sampling tube. Thus three separate samples can be drawn simultaneously with this sampler from three different points 11 inches apart in the furnace. This construction saves the handling of three separate samplers which would require six water connections, whereas with the triple sampler two water connections are all that is necessary.

All the joints on the part of the sampler protruding into the furnace are brazed; all other joints are soldered. Both samplers, B and C, are much lighter than A, and can be handled much more easily. Another of their advantages is that they can be inserted into the furnace through a much smaller opening than sampler A.

COMPARISON OF GAS SAMPLES OBTAINED WITH THE BOX SAMPLER RECOMMENDED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS AND WITH A SINGLE PERFORATED TUBE.

Figure 74 shows the results of sampling gas simultaneously with the gas sampler recommended by the American Society of Mechanical Engineers and a single small pipe a few inches above it, reaching across the stack base and perforated with small holes, as described on page 32. It will be noticed that the multitubular sampler gave a more even line, on account of its containing a large storage space. The daily average for the two was the same within 0.1 per

FIGURE 74.—Curves showing the percentages of CO_2 in the flue gas as determined from samples taken with a multitubular gas sampler (No. 1) and with a single-tube gas sampler (No. 2).

cent. But this excellent showing with the multitubular sampler was obtained only by constant care of it, for it gave a great deal of trouble from leakage.

The current of gas through the small tubes of the multitubular sampler was so slow that soot and small particles of ash settled in them and hardened, thus gradually stopping the openings. Those tubes taking samples from that portion of the gas stream carrying the most soot and ash became stopped sooner than the others. Thus the multitubular sampler lost the apparent advantage which led to its design—the advantage of drawing a sample from every portion of cross section of the gas passage—and thereby lost also its value as a sampler. It may be stated here that when the sampler was taken out after two years of usage about three-fourths of the sampling tubes were found to be stopped up, although the sampler had often been blown out with steam. One of the disadvantages of the sampler is its tendency to level all readings, so that the man running

the fire can not depend on it for guidance as much as he can on the single-tube sampler. For these reasons the multitubular sampler recommended by the American Society of Mechanical Engineers was permanently discarded.

GAS-MIXING STRUCTURES IN THE COMBUSTION CHAMBER.

On most of the tests made at the fuel-testing plant there were special fire-brick constructions of some kind in the combustion chamber to facilitate the mixing of the volatile combustible and the oxygen of the air. The first mixing wall shown in figure 4 was built in connection with the Hughes automatic smoke preventer. It lasted only

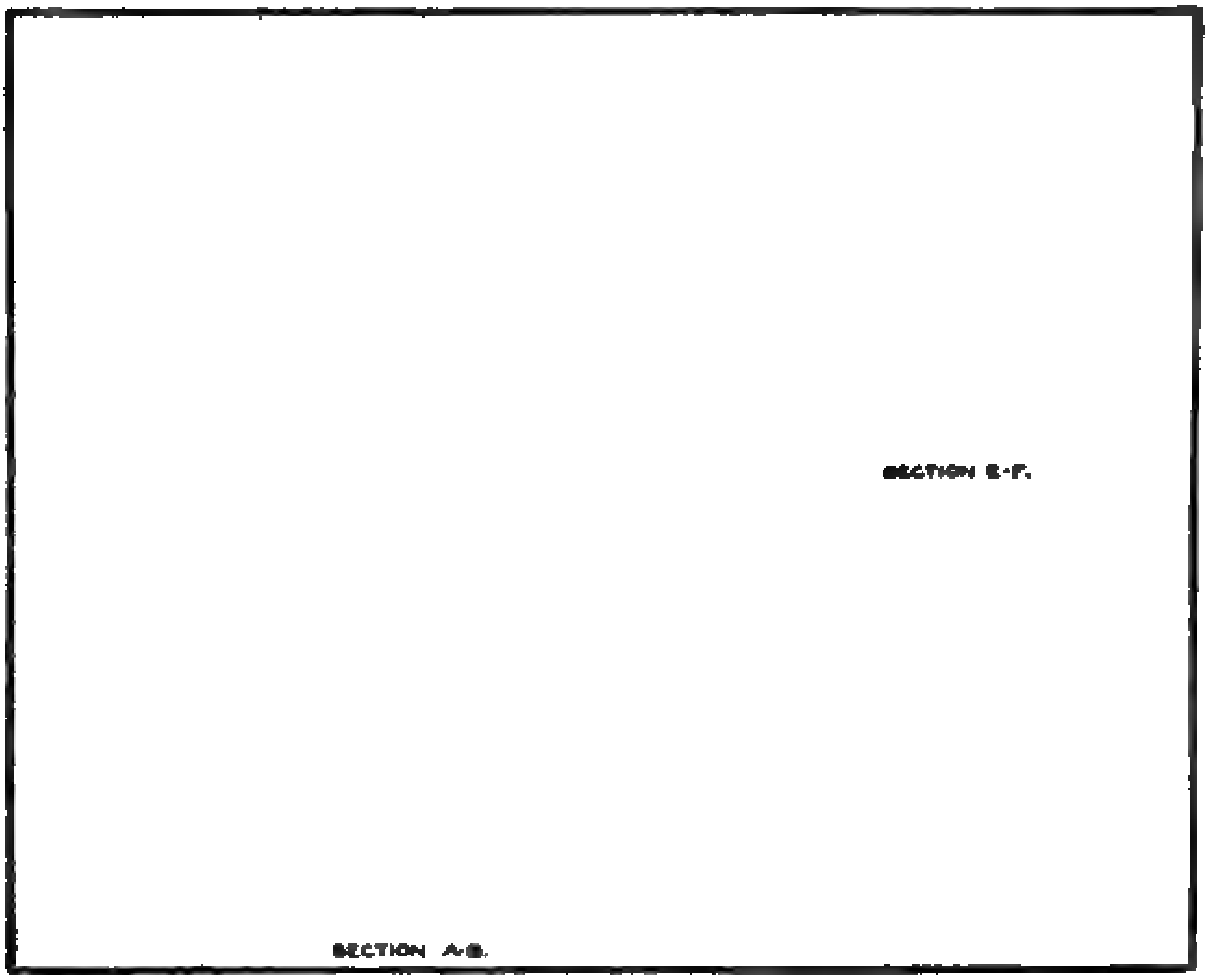


FIGURE 75.—Gas-mixing wall built in the combustion chambers of boilers Nos. 1 and 2.

about two weeks and was not thereafter rebuilt during the series of the first 78 tests. During April and May, 1905, several attempts were made to build a mixing wall out of ordinary fire brick. However, all these attempts failed, the wall melting down after two or three days' run. It was concluded that only large blocks made of the best material could for any length of time stand the high temperature and the slagging action of the gases. Consequently, a baffling wall, as shown in figure 75, was built of large fire-clay blocks 18 by 12 by 6 inches. These fire-clay blocks were said to be the best material that could be obtained. The wall was built in three portions. The bottom consisted of seven blocks set up vertically

and forming pillars for an arch of six similar blocks laid diagonally across. The space between the arch and the tile roof was completely filled with ordinary fire brick of a good grade, so that only the space between the pillars was left for the passage of the gases. The intention was to direct the stream of gases against the upper solid portion of the wall and break it into many small streams, thus obtaining an effect similar to that of a stream of water run against a solid wall. To further mix the gases, six additional large blocks were set up vertically back of the mixing wall and immediately in front of the six openings between the pillars. It would seem that the eddies caused by these obstacles in the path of the gases greatly aided the mixing.

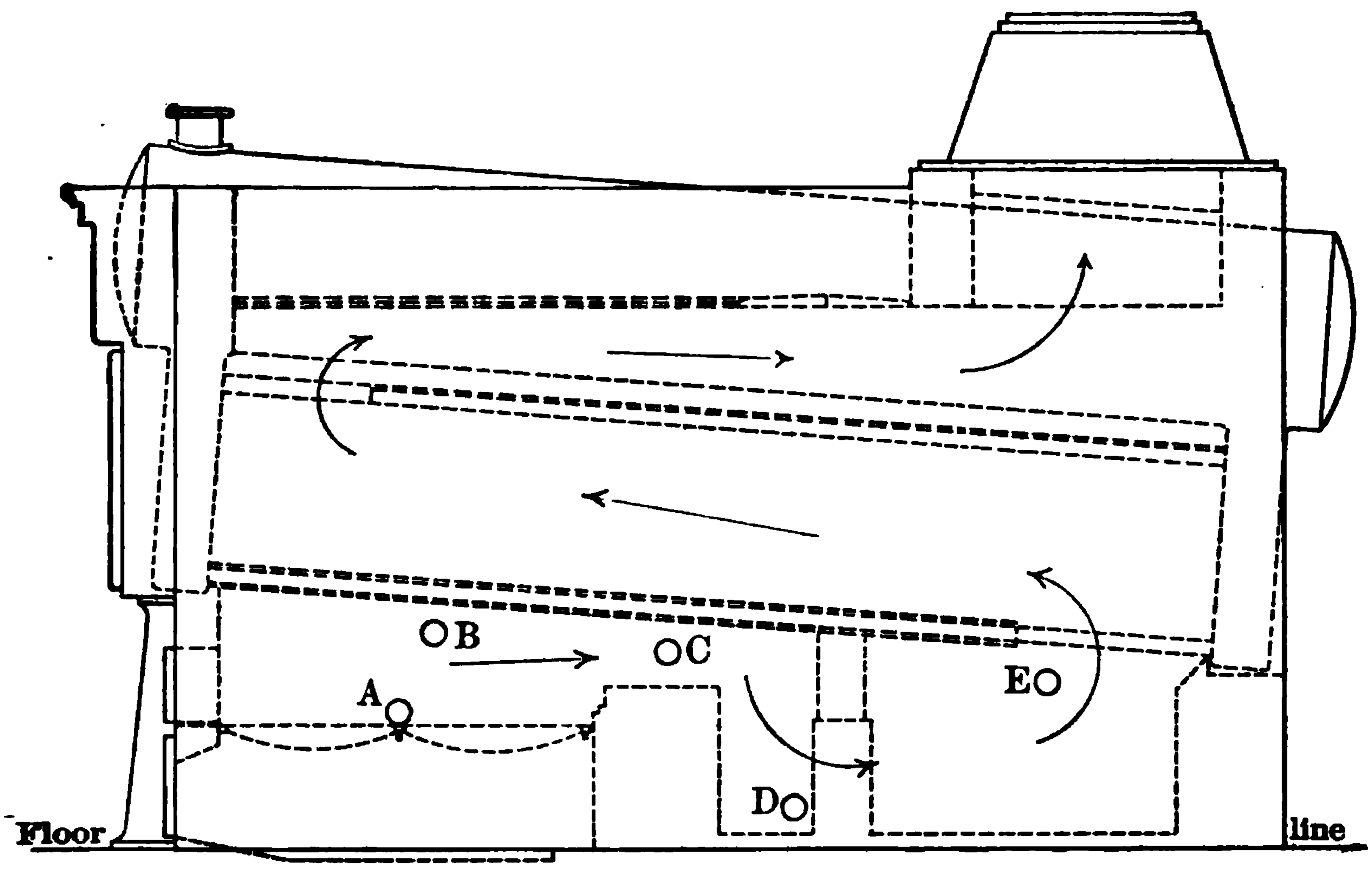


FIGURE 76.—Side elevation of boiler setting, showing openings in the walls for taking temperature measurements.

The first gas-mixing wall of this construction lasted about four months. It must be stated, however, that the tests made during this period were run below the rated capacity of the boiler, a fact that no doubt increased the life of the mixing wall. Later, when very hot fires and high-capacity tests were run, the mixing walls lasted from two weeks to a month. In these tests the temperature at the foot of the mixing wall was 3,000° F., or even higher.

The following are representative temperatures at five places in the furnace. Each value is the average of 10 readings taken with the Wanner optical pyrometer. The individual readings were taken successively through the openings A, B, C, D, and E, shown in figure 76, so that the given averages show temperatures taken nearly simultaneously at the five places.

Furnace temperatures taken during test No. 359.

	°F.
Temperature of fuel bed (A)	2,470
Temperature above fire (B)	2,586
Temperature over bridge wall (C)	2,826
Temperature at the base of mixing wall (D)	2,989
Temperature in rear of combustion chamber (E)	2,447

The fact that on two occasions an exposed platinum and platinum-rhodium couple, inserted through opening D, melted after an exposure of about 30 seconds is strong evidence of the high temperature to which the mixing wall was subjected. These mixing walls were finally abandoned and replaced by piers of small fire brick set on top of the bridge wall. The mixing walls, however, were far more efficient as smoke preventers and heat regenerators, although they retarded the draft considerably.

Just how much the over-all efficiency of the steam-generating apparatus was increased by the use of such mixing structures as are shown in figure 75 is difficult to say. The experimenters have never been able to obtain any definite and reliable figures. All that the authors can say is that it was a general belief among the members of the section that the efficiency was increased 1 to 3 per cent by such a mixing structure. To obtain definite figures it would be necessary to make many tests with the same coal in the same furnace with and without such a mixing wall.

EFFECT OF THE SPECIAL AIR-TIGHT BOILER SETTING ON ECONOMY.

In Part I, pages 22 to 24, a description is given of a special boiler setting which was entirely inclosed in an air-tight, sheet-iron casing. The object of erecting this setting was to determine (*a*) whether air spaces in the side walls reduce the radiation losses and thereby increase the efficiency; (*b*) whether by preventing air leakage the heat loss in the chimney gases was reduced and the efficiency raised. It was further desired to obtain undiluted samples of flue gases, so that an accurate heat balance could be computed.

It is to be regretted that no special investigation regarding the composition of gases at various places inside the boiler setting was possible and that no special gas analyses were made which would give exact figures on the effectiveness of the sheet-iron casing to prevent leakage. Soon after the setting was erected several members of the steam-engineering section were detailed to make steaming tests on briquetted coals elsewhere and hardly enough men were left at the plant to take the regular observations.

There were in all 85 steaming tests made with this special boiler setting. Table 12 shows how the average efficiency of the 85 tests compares with the average efficiency of 208 tests made on boilers with the standard brick setting.

The figures in the table show that nothing whatever was gained in efficiency. What was gained by the air-tight setting was perhaps lost by increased radiation. The double fire door exposed too much iron surface directly to the fire and thus increased the radiation from the front of the furnace. Furthermore, the temperature of the sheet-iron casing on the sides of the boiler often rose above the boiling point of water, indicating that too much heat passed through the air spaces in the side walls.

TABLE 12.—*Comparison of the efficiencies obtained with standard brick settings and the special hollow-tile and air-tight boiler setting.*

Type of setting.	Number of tests averaged.	Combined efficiency of boiler and combustion space (per cent).	
		Geometrical average.	Arithmetical average.
Standard brick	208	65.34	65.43
Hollow-tile and air-tight	85	64.69	64.79

It is generally believed that since air is a poor conductor of heat, air spaces built into the walls of a furnace will prevent or reduce heat dissipation through the walls. There may be a few instances in which such construction of furnace walls reduces the rate of heat flow through them; however, in most cases the effect of the air spaces is just the opposite. Although heat travels very slowly through air by conduction, it leaps over the air space readily by radiation.

It may be stated here that the amount of heat passing through a given portion of a solid wall by conduction depends on the difference of the temperatures of the two planes limiting that portion of the wall. The amount of heat passing across a given air space by radiation depends upon the difference of the fourth powers of the absolute temperatures of the surfaces inclosing the air space. The laws governing the rate of heat transmission by conduction and by radiation are expressed by the following two equations:

(1) Heat transmitted by conduction $= H = \frac{c}{d}(T - t)$,

where c is the heat conductivity of the material of the wall; T and t are the temperatures of the wall material in any two parallel planes not separated by air space; and d is the distance between the two planes.

(2) Heat transmitted by radiation $= H = C(T_1^4 - T_2^4)$,

where C is the constant of radiation and T_1 and T_2 are the absolute temperatures of two surfaces separated by an air space.

It can be readily understood from the nature of the two equations that in the case of the heat conduction through a solid portion of the

wall the loss remains approximately the same so long as the difference in temperature of the two planes remains constant, no matter what the temperature of the two planes may be. On the other hand, the heat passing across the air space by radiation increases rapidly with the temperature of the inclosing surfaces, although the difference between their temperatures may remain constant. It follows that the air space which is advantageous in the walls of a refrigerator because the temperatures are low is objectionable in furnace walls because the temperatures are high. If it is necessary to build furnace walls double on account of unequal expansion, the space between the two walls should be filled with some solid, nonconducting material. This statement has been confirmed by experiments made at the testing plant in Pittsburgh, Pa., which are described in Bulletin 8 of the Bureau of Mines, entitled "The Flow of Heat through Furnace Walls."

Returning to the results of the tests made with the special setting, it may be said in favor of the latter that the coals tested were perhaps of lower grade than the coals tested with the standard setting. Taking this probability into consideration, the efficiencies of the two settings were about the same.

As far as accuracy of data is concerned, it must be said that the flue-gas analyses and the measurements of flue-gas temperatures were much more consistent with the special setting, although credit must be partly given to the apparatus in the stack where temperatures and flue-gas samples were taken.

COMPARISON OF RESULTS OBTAINED ON BOILERS NOS. 1 AND 2 WITH THOSE OBTAINED ON BOILERS NOS. 5 AND 6.

Boiler No. 6 was provided with a special horizontal baffle that caused the gases to pass twice through the tube space of the boiler without passing under the steam drum. A full description of this special baffle is given on pages 26 and 27. The object of this method of baffling was to lengthen the path of the gases through the tubes of the boiler, thereby increasing the length of contact (or rather the number of contacts) of each particle of gas with the heat-absorbing surface of the tubes. The longer the contact the greater is the heat exchange between the gases and the heating surface. Therefore boiler No. 6 should show a greater heat absorption than boilers Nos. 1, 2, 4, and 5.

Figure 77 compares the heat-absorbing properties of boiler No. 6 with those of No. 5. The abscissas on the plat are the temperatures in the combustion chamber and the ordinates are the drops in the temperature of the gases as they pass through the two boilers. The temperature drops are due to the absorption of heat by the boilers' heating surfaces, and therefore are the measures of the heat-absorbing

properties of the two boilers. Curve No. 1 shows how much boiler No. 6 reduces the temperature of the gases, and curve No. 2 shows the same thing for boiler No. 5. Thus the plat shows that when the combustion-chamber temperature in both boilers is 2,100° F., boiler No. 5 reduces it by 1,510° F., whereas boiler No. 6 reduces it by 1,610° F. If the temperature of the steam in both boilers is taken as 350° F., the available temperature drop is $2{,}100-350=1{,}750°$ F. Therefore boiler No. 5 absorbs $\frac{1{,}510}{1{,}750}=86.3$ per cent, and boiler No. 6, $\frac{1{,}610}{1{,}750}=92$ per cent of the available heat. Again, when the temperature of the combustion chamber is 2,600° F. boiler No. 5 reduces the

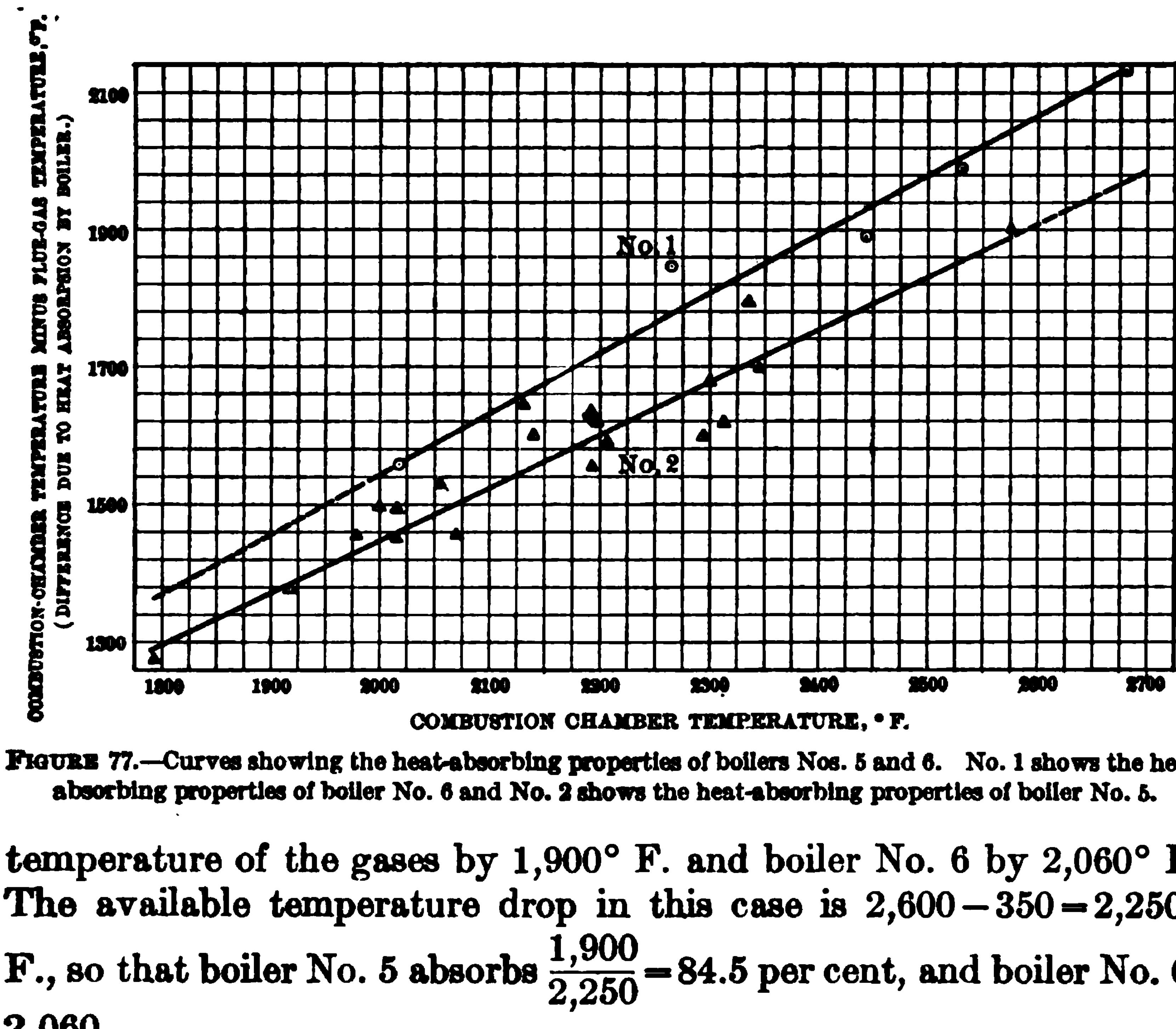


FIGURE 77.—Curves showing the heat-absorbing properties of boilers Nos. 5 and 6. No. 1 shows the heat absorbing properties of boiler No. 6 and No. 2 shows the heat-absorbing properties of boiler No. 5.

temperature of the gases by 1,900° F. and boiler No. 6 by 2,060° F. The available temperature drop in this case is $2{,}600-350=2{,}250°$ F., so that boiler No. 5 absorbs $\frac{1{,}900}{2{,}250}=84.5$ per cent, and boiler No. 6, $\frac{2{,}060}{2{,}250}=91.6$ per cent of the heat available for absorption. This calculation based on temperatures indicates that boiler No. 6 is about 6 per cent better as a heat absorber than boiler No. 5, taking the utmost available heat absorption as 100 per cent.

Table 13 shows how the efficiency of boiler No. 6 compares with the efficiency of boiler No. 5, and also with that of boilers Nos. 1 and 2. In the second horizontal line the efficiencies are given just as the averages were obtained from the results given in Table 14.

In this line the efficiency of boiler No. 6 is 0.5 per cent below that of boiler No. 5, and 2.4 per cent above that of boilers Nos. 1 and 2.

It should be noted, however, that the average capacity of boiler No. 6 is considerably higher than that developed by the other boilers. If all boilers developed the same capacities boiler No. 6 would show a marked improvement in efficiency over the other boilers.

On the basis of the general relation between the capacity and the efficiency, as indicated in figures 17, 20, and 23, the efficiencies of the second line of Table 13 have been reduced to a common capacity of 95.5 per cent, and are given in the fourth vertical column. This reduction makes the efficiency of boiler No. 6 0.6 per cent higher than that of boiler No. 5 and 4.2 per cent higher than the efficiency of boilers Nos. 1 and 2. Inasmuch as boiler No. 5 was baffled in exactly the same way as boilers Nos. 1 and 2 the superiority of outfit No. 5 over those of Nos. 1 and 2 lies in the mechanical stoking device. Better combustion was undoubtedly obtained with the underfeed stoker than with the hand-fired furnace.

TABLE 13.—*Comparison of the efficiency of boilers Nos. 1 and 2 with that of No. 5 and No. 6.*

Boiler No.	Number of tests averaged.	Average combined efficiency of boiler and combustion space (column 81, Table 4).	Average capacity developed.	Probable combined efficiency of boiler and combustion space if all boilers developed same capacity of 95.5 per cent.
1,2	401	64.5	92.6	63.8
5	23	67.4	95.5	67.4
6	6	66.9	104.4	68.0

If the figures in the last column of Table 13 can be trusted, the following conclusions can be drawn: By substituting the underfeed stoker for the hand-fired furnace of boiler No. 1 the efficiency is improved about 3.5 per cent; by retaining the hand-fired furnace of boiler No. 1 and baffling the boiler for double pass of gases through the tube spaces, the efficiency is improved about 4.2 per cent. In the first case the improvement is due to better combustion, and in the second case it is due to better heat absorption by the boiler by reason of the changed baffling.

In judging the reliability of the figures given in Table 13, the fact should be considered that the tests made on boilers Nos. 1 and 2 were made with coals coming from all over the country, whereas the tests made on boilers Nos. 5 and 6 were made with high-grade coals coming from the New River region. On this account the efficiency of boilers Nos. 1 and 2, as given in the table, is perhaps 1 per cent, or thereabout, too low.

MEASURING THE TEMPERATURE OF GASES AMONG BOILER TUBES.

During the second year's operation of the fuel-testing plant at St. Louis, Mo., attempts were made to measure the temperature of the gases as they passed among the tubes of the Heine boiler. Ten thermocouples, about 22 feet long, were inserted among the tubes of the boiler through the staybolt holes in the front water leg. These thermocouples were long enough to reach the entire length of the gas path through the tube space. They were made of copper and German-silver wire, as it was not expected that the temperature would be high enough to materially effect these metals, and platinum couples were out of the question on account of their high cost. The wires of the thermocouples were insulated with hard glass tubing and placed within standard ⅜-inch iron pipes of suitable length. The junctions of the wires projected about ½ inch out of the iron pipe. The space between the wires and the inside of the iron pipe at the cold end of the pipe was well filled with cotton waste to prevent cold air from being drawn into the pipe and cooling the couple.

It was planned to insert these thermocouples successively into each horizontal row of staybolt holes and measure the temperature of the gases for each foot of length in the spaces between two adjacent horizontal rows of tubes. Starting with the top horizontal row of staybolt holes the junctions of the thermocouples were placed 1 foot from the front water leg. After two or three minutes, allowed for the couples to be heated to the temperature of the gases, readings of the thermocouples were taken in rapid succession so as to make these readings as nearly simultaneous as possible. The junctions of the thermocouples were then moved 1 foot farther from the front water leg and another series of 10 readings was taken, and so on until the temperatures along the entire length of the tube space were obtained. The thermocouples were then placed in the next row of staybolt holes below. This procedure was to be repeated until the temperatures in all the spaces were obtained. To facilitate rapid reading of temperatures, the thermocouples were connected to a 10-point switch.

After the readings in several rows were obtained and studied, these temperature measurements were found to be inconsistent, and the investigations were abandoned. The temperatures indicated by the couples were very much the same throughout the full length of the tubes, and were too low. The reason for such results was that the junctions of the thermocouples were too close to the boiler tubes and were so completely surrounded by the water-heating surfaces that the couples measured the temperature of the surfaces rather than that of the gases. It should be stated here that at first the temperatures were thought to be low because the ends of the pipes containing the junctions of the thermocouples rested on the tubes, as shown by thermocouple B, figure 78.

The ends of the iron pipes containing the couples were, therefore, bent upward, so that the junction of the wires would be in position as shown by thermocouple A, but no marked improvement was obtained. The cooling of the thermocouple junctions took place principally by radiation rather than by conduction. What actually happened was this: The hot gases imparted heat to the junc-

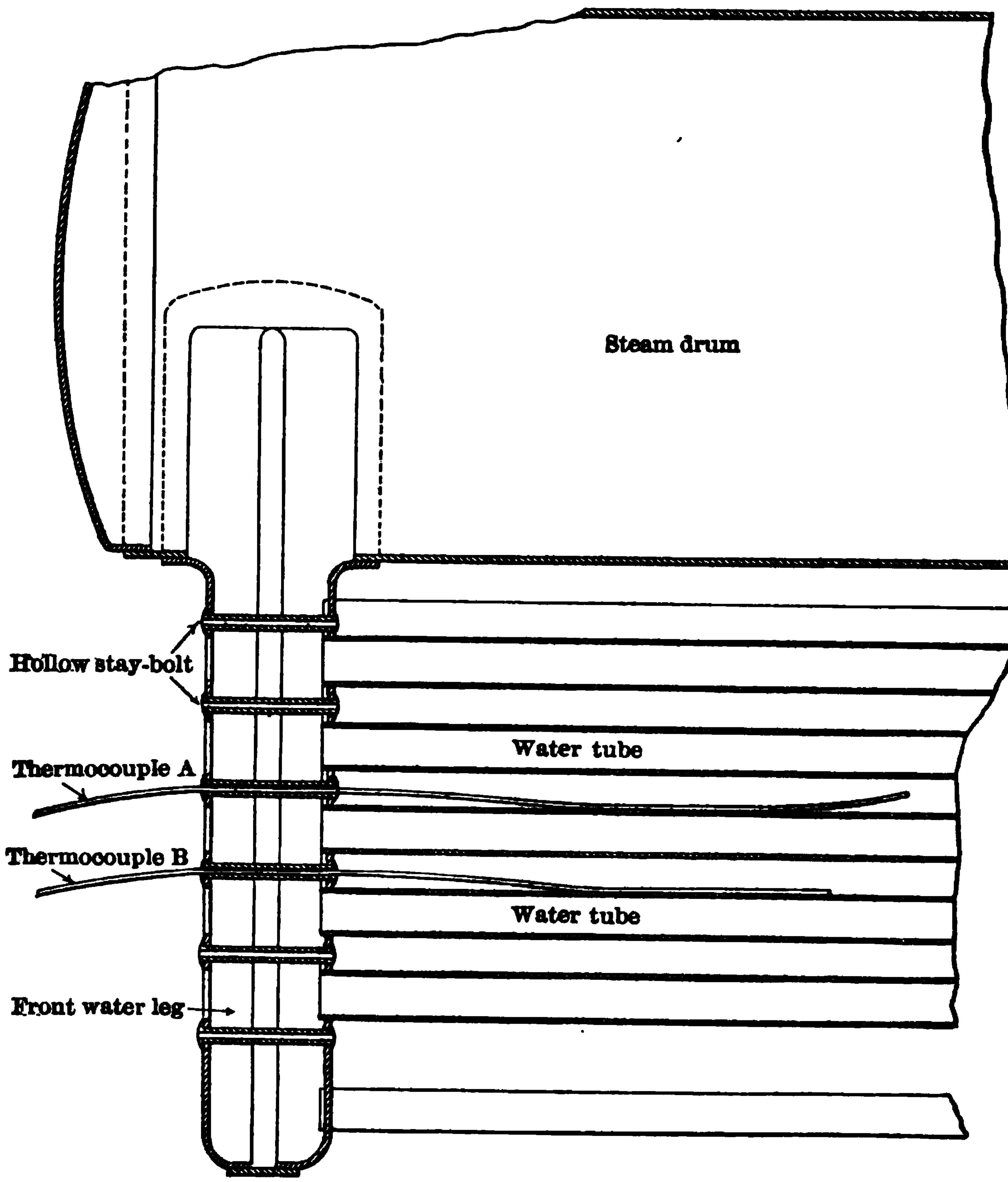


FIGURE 78.—Diagram showing method of measuring temperatures among boiler tubes.

tion of the thermocouple by convection; that is, some of the particles of the gas came into actual contact with the junction and transferred to it part of the heat that they contained. As soon as the junction absorbed this imparted heat its temperature rose above that of the surrounding tubes and heat was radiated from the junction to the cooler surfaces of the tubes;[a] consequently there was a con-

[a] For the law governing the rate of heat transfer by radiation, see p. 244.

stant exchange of heat in the junction; heat was received by it from the gases, and again radiated to the tubes. When equilibrium was acquired, that is, when the thermocouple indicated a constant temperature, the heat received from the gases was exactly equal to the heat radiated to the tubes. When the temperature of the junction was constant it was, for the reason stated above, somewhere between the temperature of the gases and that of the surfaces of the tubes. The investigation has shown that it was much closer to the temperature of the tubes than to that of the gases.

Although the above investigation failed in its primary purpose, which was to obtain the temperature drop of the gases as they passed among the tubes, it revealed the fact that it is difficult to measure the temperature of gases surrounded by surfaces cooler or hotter than the gases themselves.

One may say that it is impossible, with ordinary direct methods, to measure the temperature drop of the gases as they pass through any boiler. By direct methods is meant any method which is based on the assumption that a thermometer bulb or a thermocouple, or any other solid object placed within the stream of gas will be raised to the same temperature as the gas. Such assumption would be very nearly true if there were no heat loss or heat gain on the part of the inserted object to or from the surrounding surfaces.

THE INCORRECTNESS OF FLUE-GAS TEMPERATURES AS USUALLY OBTAINED.

The investigations described in the preceding section cast considerable light on the accuracy of the measurements of flue-gas temperatures. Usually the thermometer is inserted in the breeching, or in the uptake where the bulb of the thermometer is exposed to wall or metallic surfaces which are cooler than the gas scrubbing the thermometer bulb. The thermometer constantly radiates heat to these surfaces; therefore the thermometer bulb is cooler than the gases passing it. The nearer the thermometer to the boiler's surfaces, the lower will be, in general, the reading of the thermometer; the extreme of such misleading readings may be obtained by placing the thermometer among the water tubes of a boiler.

The following is an actual case of very low flue-gas temperature measurement which was caused by placing the thermometer too near the heating surfaces of tubes. Recently one of the authors visited a Pittsburgh boiler plant where tests were being conducted with a special furnace equipment. The engineer in charge showed him tabulated results of a boiler test made with the equipment. These were some of the items:

Steam pressure at gage, pounds	162
Flue-gas temperature, °F	386
Efficiency, per cent	78
Temperature corresponding to 162 pounds pressure, °F	371

The above figures show that the flue-gas was only 15° F. hotter than the water in the boiler. This would be a very good heat absorption indeed if the temperature measurements were correct. However, on investigation of the methods employed in the measurements of the flue-gas temperature it was found that the thermometer was inserted among the tubes at the end of the third pass of the usual Babcock & Wilcox three-pass boiler. What the thermometer really did measure was the temperature of the surrounding tubes. The actual temperature of the gases at that place was perhaps 200 to 300° F. higher.

As another instance of low flue-gas temperature readings can be given the results obtained in a test made on a Stirling boiler at the Williston plant of the United States Reclamation Service.[a]

The principal parts of the boiler and setting are shown in figure 79.

The coils of horizontal tubes shown at the end of the last gas passage are preheaters for air to be introduced into the furnace through openings in the bridge wall. For the purpose of measuring flue-gas temperatures a mercury thermometer was inserted into the uptake through an opening in the top rear door; its location in the uptake is shown in the figure. The bulb of the thermometer was about 1 foot above the preheating coils, midway between the wall and the rear drum, and about 3 feet below the damper. The distance between the wall and the rear steam drum was 18 inches. The top half of the nest of preheating tubes received the cold air directly from a fan blower, and the temperature of the tubes was perhaps 100 to 150° F. The temperature of the rear steam drum was probably below 352° F., the temperature of steam corresponding to 125 pounds gage pressure. The temperature of the top rear door was not, perhaps, over 100° F. The temperature of the damper above was probably 500° F. The thermometer bulb received heat from the gases which were scrubbing against it, and radiated heat to the comparatively cold surfaces surrounding it; therefore, the thermometer indicated a temperature considerably below that of the gases. This fact was discovered by placing another thermometer in the hood of the stack about four feet above the damper. The hood of the stack extended over the uptake of another boiler which formed one battery with the test boiler. During the testing this other boiler was banked and the flue gases which were at a very low temperature entered the same hood of stack as the gases from the test boiler. There was no partition separating the two halves so that the cool gases from the banked boiler could partly mix with those from the test boiler and lower the temperature of the gases from the test boiler. Furthermore, the sheet iron of the hood always radiated a considerable quantity of heat and was, therefore, colder than the

[a] For details of these tests see Bureau of Mines Bulletin 2.

gases on the inside. Consequently the thermometer bulb in the stack lost some heat by radiating it to the sheet iron of the hood, and was also at a lower temperature than the gas passing it. Nevertheless, the thermometer in the hood indicated a temperature which

FIGURE 79.—Boiler setting at the power plant of the United States Reclamation Service, Williston, N. Dak. The figure shows the location of two thermometers for measuring flue-gas temperatures.

was about 100° F. higher than the temperature indicated by the thermometer in the uptake. This difference of temperature was doubtless due to the close proximity of the cold preheating coils and the rear steam drum. Table 14 shows the temperature as obtained by the two thermometers.

TABLE 14.—*Flue-gas temperatures obtained at two places in a boiler setting.*

Test No.	Reading of thermometer above damper (° F.).			Reading of thermometer below damper (° F.).		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
1	442	450	435	374	400	335
2	470	500	435	373	410	350
3	559	624	320	457	510	360
4	436	470	385	379	425	325
5	473	520	420	418	460	355
6	519	555	465	448	475	400

NOTE.—After test No. 6 all readings of flue-gas temperature were taken above the damper.

It must be added that the thermometers were exchanged several times, but their indication persistently bore the same relation as regards position, no matter what thermometer was used.

Perhaps after reading this discussion the reader will better appreciate the value of the special device used in connection with measuring the flue-gas temperatures in boilers Nos. 4, 5, and 6. Often great care is taken to calibrate a flue-gas thermometer to within one degree and then the instrument is placed carelessly in the uptake or boiler setting and correct results are expected or claimed without paying any attention to the disturbing effects of cooling surfaces. Certainly no person would hang a thermometer in the sun and claim that the temperature indicated by it was the temperature of the surrounding air; or, in a parallel case, the reading of a thermometer placed between two pieces of ice in a warm room would not indicate the temperature of the air in the room. Still, when it comes to measuring the temperature of a stream of gas the indication of a thermometer is taken to be absolutely correct, because the thermometer is known to be correct, without regard to the temperature of the walls of the vessel holding the gas.

Gases are permeable to radiation, a fact that makes the correct measurements of gas temperatures a high art.

RÉSUMÉ OF SPECIAL PLANT AND FIELD INVESTIGATIONS.

The steam-engineering section made the following special investigations at the plant and in the field:

(*a*) Experiments on heat transmission as applied to steam boilers.

(*b*) Experiments relating to movement of gases through steam-generating apparatus.

(*c*) Steaming tests with briquetted and run-of-mine coal on U. S. torpedo boat *Biddle*.

(*d*) Steaming tests with briquetted and run-of-mine coal on a locomotive of the Seaboard Air Line Railway.

(*e*) Steaming tests with lignite at the Reclamation Service plant at Williston, N. Dak.

HEAT-TRANSMISSION EXPERIMENTS.

The heat-transmission experiments were made at the St. Louis plant with a laboratory apparatus consisting of a small multitubular boiler and an electric furnace. In these experiments air was heated electrically and passed at various velocities and temperatures through the flues of the boiler. The object of the experiments was to determine the effect of the temperature and the velocity of gases on the rate of the heat impartation by convection to the heating surfaces of the boiler. The heat imparted to the boiler was measured by condensing and weighing the steam made in the boiler. The initial temperature of the air was regulated by means of a water rheostat which controlled the electric current to the furnace.

The pressure drop necessary to move the air through the furnace and boiler was obtained with a steam ejector placed in the exit end of the apparatus. With this arrangement a total pressure drop up to 24 inches of water could be obtained. Five series of tests were run with initial temperatures of the air at 700, 900, 1,200, and 1,500° F. The velocity of the air through the boiler was kept constant for any one test, but varied for the different tests in the same series.

Experiments were made with four boilers, all having 10 flues of drawn copper tubing and the same external diameter, 4½ inches. Three of the boilers were 8 inches in length, and had flues of three different diameters. The object of experimenting with these three boilers was to determine the effect of the diameter of flues on the true boiler efficiency. The fourth boiler was 16 inches long; the object of experimenting with this boiler was to study the effect of the length of the flues on the true boiler efficiency.

The electric furnace was of the resistance type and consisted of six coils of pure nickel wire.

There were made with these boilers 237 reliable tests varying in length from 20 minutes to 2 hours, according to the rate of working of the boiler. High-capacity tests were short and low-capacity tests were long.

The following are the principal deductions drawn from these experiments:

When the temperature of the air entering a boiler remains constant, the rate of heat impartation to the boiler flues by convection increases nearly in direct proportion to the velocity of the air passing through the flues. This is particularly true beyond a certain velocity which is called the critical velocity.

When the velocity of the air remains constant the rate of heat impartation to the flues by convection increases when the initial temperature rises, but not in direct proportion to the rise. The increase in the rate of heat absorption becomes smaller for equal rises in the initial temperature as the latter becomes higher.

Beyond the critical velocity the true boiler efficiency is nearly constant for any rate of working and for any initial temperature.

The critical velocity increases when the temperature rises and seems to drop when the diameter of the flues is increased.

Increasing the diameter of the flues decreases their efficiency as heat absorbers; that is, flues of large diameter are less efficient than flues of small diameter of the same length, although the large flues have more heating surface. The higher efficiency of small tubes is due to the fact that the average distance of each particle of gas from the flue is shorter and therefore each particle of gas comes oftener in contact with the surface of the flues. It is not the amount of heating surface which determines the efficiency of a boiler, but the cross-sectional area of the gas passage and the arrangement of the surface with respect to the flow of gas.

Increasing the length of flues increases their efficiency, but not in direct proportion; the increase in efficiency becomes smaller with every successive addition to the length of the flues, so that increasing the length of flues beyond some certain value is not good economy.

The capacity of any boiler can be increased by passing larger weights of gases over its heating surfaces, provided that the initial temperature is the same.

The efficiency of any boiler can be increased by making the gas passages smaller in cross section in comparison to the length. This can be done either by reducing the cross sections of the individual gas passages, keeping their length the same, or by increasing the length of the gas passages, keeping their cross sections the same.

The detailed description of these heat-transmission experiments and the discussion of the results are given in Bureau of Mines Bulletin No. 18, entitled "Heat Transmission into Steam Boilers."

EXPERIMENTS RELATING TO MOVEMENTS OF GASES THROUGH STEAM-GENERATING APPARATUS.

During the months of March and April, in 1908, the steam-engineering section made a series of experiments with the object of obtaining data on which to base the study of the effects that the resistance of the fuel bed and the boiler has on the pressure drops and the weight of gases flowing through the steam-generating apparatus. A small laboratory apparatus was used which consisted of a glass tube about 1½ inches in internal diameter and 18 inches long. Within this tube, which was placed in a vertical position, were two beds of shot supported on wire screens. One of these beds, kept at a constant thickness, represented the boiler. The other bed, varied in thickness in the different experiments, represented the fuel bed. The glass tube was connected by an iron pipe to a measuring tank of 10 cubic feet capacity.

Air was made to flow through the glass tube containing the two beds of shot by filling the measuring tank with water and then emptying it. The flow of air through the tube was regulated by the manipulation of the water valve in the emptying and filling of the

tank, which was provided with a gage glass so that the amount of water in the tank could at all times be estimated. The pressure above each bed was measured by a U-tube manometer.

Experiments were made with the air flowing in either direction through the tube and beds of shot. The exact time of starting and stopping each experiment was noted. During the experiment one observer operated the water valve so as to have the air pressure indicated by the manometer as uniform as possible, the pressure seldom varying as much as 10 per cent from the average. Another observer read and recorded the air pressures and temperature as often as convenient. Thus, the duration of the test, the volume of air displaced, and its temperature being known, the rate of flow of air for each difference of pressure and each thickness of shot bed could be computed.

Laboratory apparatus was used in these experiments in preference to large boilers because of the low cost of construction and ease of manipulation. To make such experiments on large boilers would not only be too costly but also inaccurate, because on such a large apparatus it would be difficult to control the conditions so as to have only one or two varying quantities while holding the rest fixed. Those who have ever tried to get even relative figures on the resistance of hot fuel beds, or who have attempted to measure the weight of gases flowing through a boiler, will realize how difficult, not to say hopeless, a task it would be to make such experiments on a large boiler. Shot was selected for the experiments because of its regularity and uniformity of size and the comparative ease with which the aggregation of the spheroids with respect to one another can be reproduced.

In all, 125 reliable experiments were made. Two sizes of shot were tried, No. 8, which averaged about 0.0974 inch in diameter, and No. 4, having an average diameter of 0.125 inch.

The principal deductions relative to steam-generating apparatus drawn from these experiments can be stated as follows:

(*a*) When the total pressure drop and the temperature remain constant the pressure drop through the fuel bed increases when the resistance of the bed increases, although the exact relation may not be a direct proportion.

(*b*) When the thickness of the fuel bed is increased the pressure drop through it must be increased in the same proportion if the weight of air is to remain the same; that is, when the thickness of the fuel bed is doubled the pressure drop through it must be doubled if the weight of air passed through it is to remain constant.

(*c*) When the total pressure drop from ash pit to uptake remains constant the weight of gas passing through the steam-generating apparatus decreases when the pressure drop through the fuel bed increases. This deduction follows from the deduction under (*a*).

(*d*) When the pressure drop through the fuel bed and the thickness of the bed remain constant the weight of air passing through it will increase with the size of the coal; the relation between the two seems to be approximately a direct proportion.

Further details and the results of these experiments can be found in Bureau of Mines Bulletin 21.

TESTS OF RUN-OF-MINE AND BRIQUETTED COAL ON THE TORPEDO BOAT BIDDLE.

The fuel tests conducted at Norfolk included a detailed investigation of a number of Virginia and West Virginia coals that are bought by the United States Government for the Navy and for use in constructing the Panama Canal. The same coals are also extensively used by the merchant marine, manufacturing plants, and railroads. Through a cooperative arrangement with the Navy Department steaming tests of the coals were undertaken with the object of determining the relative merits of the same coal when burned in run-of-mine form or as briquets under marine boilers.

The tests were made on board the U. S. torpedo boat *Biddle*, designated for that purpose. The results of these tests were published in United States Geological Survey Bulletin No. 403, and have been reprinted in Bureau of Mines Bulletin 33.

The main object of these tests was to determine whether the use of briquetted coal on torpedo boats has any advantages over the use of run-of-mine coal. Besides the economy obtained with briquetted and with raw coal, the following properties of the two fuels were given particular attention: (*a*) The tendency to smoke; (*b*) the amount of sparks emitted from the stack; (*c*) the rate at which steam can be made and the ease with which the fires are handled; (*d*) the ease of transferring fuel from the coal bunkers into the fireroom.

The coal used in these tests was all run-of-mine and came from four different mines, all of which are located on the Chesapeake & Ohio Railway, and in the New River coal field.

Jamestown No. 6 coal came from the Sewell bed at Red Star, Fayette County, W. Va.; Jamestown No. 9 coal came from the Sewell bed, mined near Winona, Fayette County, W. Va.; Jamestown No. 10 coal came from the Beckley bed, at Stanaford, Raleigh County, W. Va., and Jamestown No. 11 coal came from the Beckley bed, at West Raleigh, Raleigh County, W. Va.

Part of the Jamestown No. 6 coal was made into briquets, 6¾ by 4¼ by 3 inches in size, at the United States fuel-testing plant on a briquetting press built in England. The compression on these large briquets was about 2,500 pounds per square inch. The binder used was 6 per cent of water-gas pitch.

Portions of the Jamestown Nos. 9 and 11 coals were made into briquets circular in horizontal section, 3¼ inches in diameter, 2¾ inches

thick in the center, and 1¼ inches thick at the circumference. The compression on these small briquets was about 1,000 pounds per square inch. In both coals the binder used was 6 per cent of water-gas pitch.

The torpedo boat *Biddle* is 157 feet in length on load water line, 17 feet 7½ inches extreme beam, and 175 tons displacement. Its equipment includes two triple-expansion engines and two water-tube boilers. The boilers are in separate boiler rooms, one at each end of the engine compartments, the fronts of the boilers facing the latter.

The two boilers are exactly alike in size, construction, and setting (fig. 80). Only the forward boiler was used for tests. It is of the curved water-tube type known as the Normand boiler.

The furnace is placed under the steam drum between the two nests of water tubes and the mud drums. It is equipped with a plain grate for hand firing. In the front portion of the boiler on both sides, the first and second rows of tubes next the furnace are so curved and placed with respect to each other that they form a nearly gas-tight baffle. On the outside of each nest of tubes the last two rows are similarly placed along the full length of the boiler.

The products of combustion flow to the rear of the furnace, where they enter the tube nests through the spaces between the tubes, which are left open for the purpose. Through the nests of tubes the gases flow to the front of the boiler and there turn up into the hood and out through the stack.

The principal dimensions of the boiler and furnace are shown in Table 15.

TABLE 15.—*Dimensions of Normand water-tube boiler and plain-grate furnace.*

Diameter of steam drum	inches	35.43
Length of steam drum	do	150.00
Diameter of mud drums	do	10.75
Length of mud drums	do	141.75
Diameter of downcomers	do	10.75
Number of tubes		1,552
Outside diameter of tubes	inches	1$\frac{3}{16}$
Approximate length of tubes	do	75.5
Total heating surface	square feet	2,776.19
Length of furnace	feet	9.16
Width of furnace	do	6.40
Height of furnace from grate to steam drum	do	4.65
Height of furnace from grate to bend of tubes	do	3.76
Approximate combustion space above grate	cubic feet	136
Distance from front of furnace to opening among tubes	feet	5.5
Length of bars	inches	37.5
Average width of grate bars on top	do	.375
Average width of air spaces	do	.56
Air spaces in grate (approximate)	per cent	.55
Area of grate	square feet	58.6
Ratio of grate area to combustion space		2.33
Inner dimensions of stack	inches	36 x 40
Height of stack above grate	feet	15

Figure 81 shows four spark catchers in position as used during the tests. The shape of the end inside the stack is nearly a sector of a circle covering an angular area of 9°, so that the total area covered

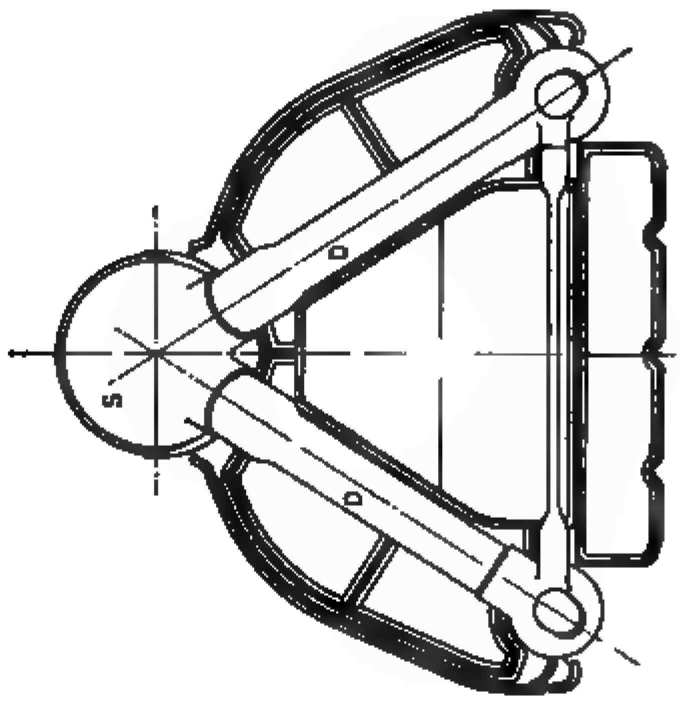


FIGURE 60.—Normand water-tube boiler and setting.

by the four spark catchers is 0.1 of the total cross-sectional area of the stack.

In starting and closing the tests a modification of the "alternate method" was used. The boiler was kept under steam pressure all night with a low fire covering the front third of the grate. About one hour before starting a test the fire was spread over the whole grate and gradually built up to 3 or 4 inches in height. During this building of the fire about 500 pounds of coal were put into the furnace. The tests were brought to a close as nearly as possible under the same conditions as they were started.

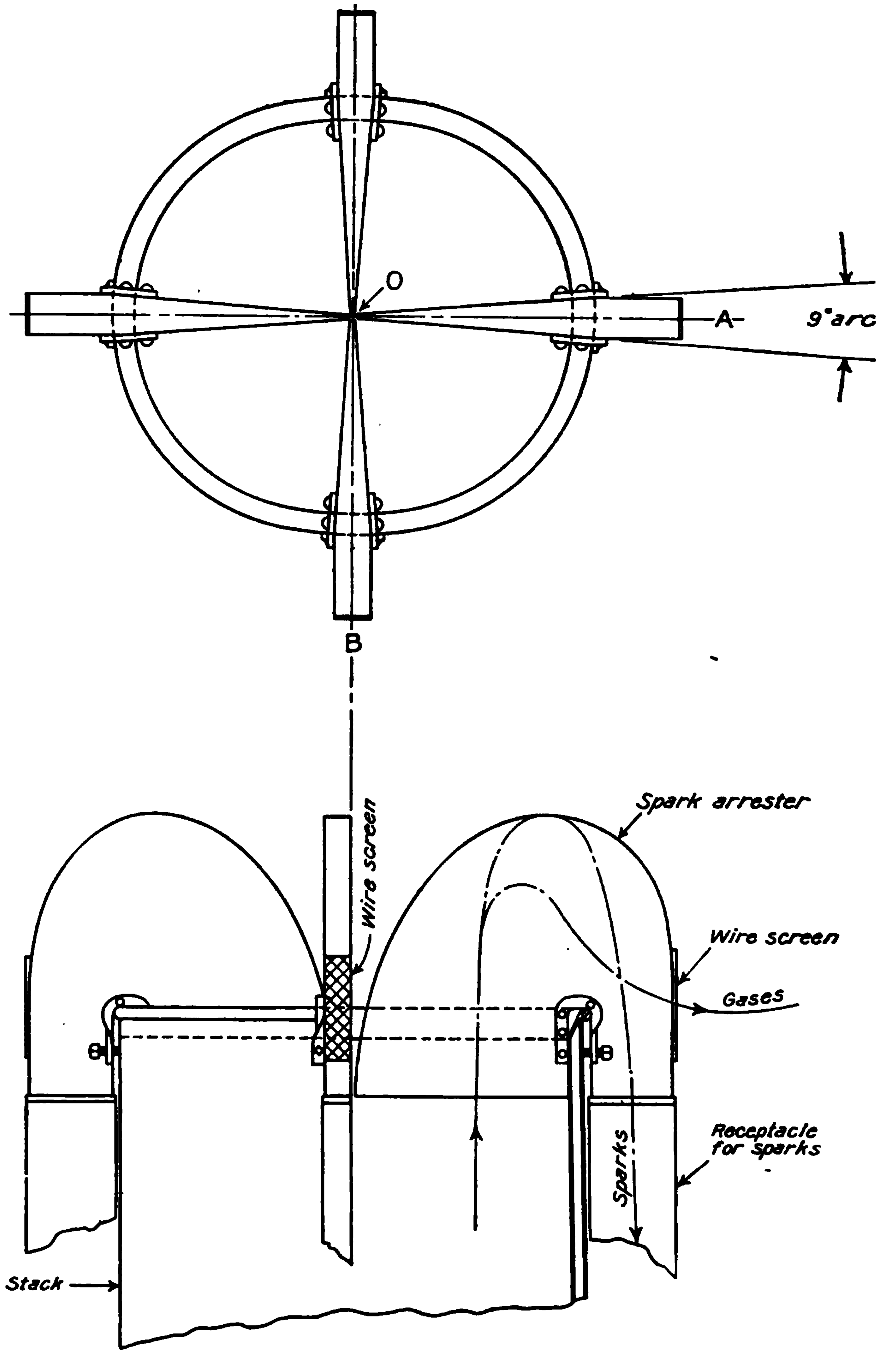
After closing a test the free ash was removed from the ash pan, weighed, and the weight charged to the test. The fire was then burned down entirely; the clinkers were pulled out through the fire doors, weighed, and also charged to the test. It was impracticable to clean the fire before the close of the test on account of the lower edge of the fire door being 14 inches above the grate.

In all, 21 tests were made; 10 with run-of-mine coal, 3 with large briquets, and 8 with small briquets. The averages of the data taken during the test and the calculated results are given in Table 16.

TABLE 16.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. "Biddle," Dec. 6, 1907, to Jan. 27, 1908.*[a]

Test No.	Designation of coal.	Form of fuel.	Date of trial.	Duration (hours).	Average pressures.		"Draft"[b] (inches of water).		
					Barometer (inches of mercury).[c]	Steam above atmosphere (pounds per square inch).	At base of stack.	Over fuel bed.	In ash pit.
1	2	3	4 (1)	5 (2)	6 (3)	7 (11.1)	8 (12)	9 (13)	10 (14)
			1907.						
1	Jamestown 6	Run of mine	Dec. 6	5.25	30	204.5	−0.11	+0.39	+1.23
2	Jamestown 6	Run of mine	Dec. 7	3.33	30	204.0	− .44	+ .98	+2.48
3	Jamestown 6	Run of mine	Dec. 10	7.15	30	199.0	− .10	+ .24	+ .57
4	Jamestown 6	Large briquets	Dec. 12	6.23	30	206.0	− .13	+ .23	+ .54
5	Jamestown 6	Large briquets	Dec. 13	5.10	30	199.0	− .16	+ .39	+ .83
6	Jamestown 6	Large briquets	Dec. 16	4.03	30	200.3	− .21	+ .83	+2.37
7	Jamestown 11	Run of mine	Dec. 18	4.70	30	203.1	− .23	+ .47	+1.13
8	Jamestown 11	Run of mine	Dec. 19	5.98	30	202.3	− .19	+ .34	+ .65
9	Jamestown 11	Run of mine	Dec. 20	4.05	30	202.8	− .51	+1.30	+2.35
			1908.						
10	Jamestown 11	Small briquets	Jan. 3	3.97	30	202.0	− .29	+ .48	+ .97
11	Jamestown 11	Small briquets	Jan. 6	4.08	30	202.0	− .50	+1.45	+2.55
12	Jamestown 11	Small briquets	Jan. 8	6.08	30	207.0	− .17	+ .27	+ .84
13	Jamestown 11	Small briquets	Jan. 10	2.37	30	203.0	− .68	+2.22	+3.39
14	Jamestown 9	Run of mine	Jan. 13	6.78	30	204.1	− .14	+ .36	+ .79
15	Jamestown 9	Run of mine	Jan. 14	4.62	30	203.0	− .33	+ .57	+1.33
16	Jamestown 9	Run of mine	Jan. 17	4.30	30	202.8	− .74	+1.50	+3.95
17	Jamestown 9	Small briquets	Jan. 20	5.30	30	203.9	− .11	+ .27	+ .83
18	Jamestown 9	Small briquets	Jan. 21	4.20	30	205.0	− .29	+ .88	+1.76
19	Jamestown 9	Small briquets	Jan. 23	3.85	30	200.0	− .55	+1.97	+3.73
20	Jamestown 11	.....do........	Jan. 25	1.58	30	201.0	− .60	+2.32	+4.92
21	Jamestown 10	Run of mine	Jan. 27	4.10	30	204.0	− .16	+ .77	+1.67

[a] Code numbers (in parentheses at the top of certain columns) refer to corresponding items described in Bulletin U. S. Geological Survey No. 325, pp. 151–153.
[b] The word "draft" is placed in quotation marks because it is misused when applied to the moving of gases or to the pressure difference which causes them to move.
[c] Taken as constant.



SECTION THROUGH STACK ON A-O-B

FIGURE 81.—Spark catchers for Normand boiler and their attachment to stack.

TABLE 16.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. "Biddle," Dec. 6, 1907, to Jan. 27, 1908*—Continued.

Test No.	Revolutions per minute of fan.	Average temperatures (°F.) of— At-mosphere.	Steam.	Feed water in tank.	Gases leaving boiler tubes.	Furnace.	Moisture in fuel (per cent).	Fuel (total weight in pounds). As fired.	Dry.	Ash and refuse.	Clinker in ash and refuse (per cent).
1	11 (14.5)	12 (15)	13(17)	14(18)	15 (21)	16(22.1)	17 (26)	18 (25)	19 (27)	20 (28)	21 (29)
1	....	54	380	50	739	2,673	1.64	9,171	9,021	1,423	16.65
2	....	53	380	50	739	2,615	1.50	8,076	7,955	642	41.90
3	312	66	......	51	646	2,367	1.64	8,283	8,147	739	24.90
4	276	44	381	51	681	2,460	1.76	7,771	7,634	707	32.11
5	347	40	378	50	802	....	1.48	8,678	8,550	519	32.18
6	544	57	379	51	919	2,586	1.78	10,778	10,586	615	39.51
7	426	60	380	50	655	2,273	1.92	8,368	8,207	666	21.62
8	324	45	379	50	597	2,347	2.91	7,249	7,038	828	26.40
9	635	49	380	50	728	2,624	2.50	10,941	10,667	605	35.70
10	389	45	379	50	696	2,662	1.26	7,390	7,297	487	34.70
11	626	43	379	49	797	2,921	1.87	10,912	10,708	643	23.48
12	320	49	380	49	583	2,633	1.57	7,313	7,198	617	28.04
13	744	40	379	49	807	3,097	1.79	9,074	8,912	351	15.10
14	357	47	......	49	583	2,502	2.55	8,530	8,312	597	28.81
15	436	42	383	49	668	2,881	2.29	8,224	8,036	481	36.59
16	701	42	383	49	716	....	2.81	13,375	12,999	839	38.74
17	309	55	383	48	637	2,442	1.39	7,464	7,360	485	30.93
18	375	60	384	48	709	2,765	1.71	9,239	9,081	423	45.15
19	382	50	382	50	752	2,950	2.36	11,836	11,557	447	32.89
20	750-800	31	380	45	817	3,070	1.79	6,670	6,551	343	44.02
21	....	44	383	47	601	2,498	2.61	7,098	6,913	432	69.44

Test No.	"Combustible"* [a] consumed (pounds).	Ash and refuse in dry fuel (per cent).	Proximate analysis (per cent). Fixed carbon. In moist coal.	Fixed carbon. In "combustible."	Volatile matter. In moist coal.	Volatile matter. In "combustible."	Moisture. In fuel as fired.	Moisture. Accompanying 100 per cent "combustible."	Ash.	Sulphur (separately determined). Moist basis.	Dry basis.
1	22 (30)	23 (31)	24 (32)	25	26 (33)	27	28 (34)	29	30 (35)	31 (36)	32 (41)
1	7,738	15.77	74.29	79.97	18.61	20.03	1.64	1.77	5.46	0.76	0.77
2	7,167	8.07	73.57	79.97	18.43	20.03	1.50	1.63	6.50	.71	.72
3	7,427	9.07	74.57	79.20	19.58	20.80	1.64	1.74	4.21	.65	.66
4	6,967	9.26	70.75	75.74	22.66	24.26	1.76	1.88	4.83	.90	.92
5	7,864	6.07	70.54	75.32	23.11	24.68	1.48	1.58	4.87	.89	.90
6	9,804	5.81	72.34	77.56	20.93	22.44	1.78	1.91	4.95	.86	.88
7	7,364	8.12	77.54	83.96	14.81	16.04	1.92	2.08	5.73	.70	.71
8	6,243	11.76	74.69	81.98	16.42	18.02	2.91	3.19	5.98	.97	1.00
9	9,694	5.67	74.32	81.89	16.44	18.11	2.50	2.75	6.74	.73	.75
10	6,684	6.67	75.71	81.48	17.21	18.52	1.26	1.36	5.82	.78	.79
11	9,740	6.00	74.21	80.52	17.95	19.48	1.87	2.03	5.97	.80	.82
12	6,529	8.57	75.11	81.16	17.43	18.84	1.57	1.70	5.89	.77	.78
13	8,195	3.94	74.48	80.64	17.88	19.36	1.79	1.94	5.85	.86	.88
14	7,422	7.18	67.46	74.98	22.51	25.02	2.55	2.83	7.48	.61	.63
15	7,291	5.99	68.98	75.81	22.01	24.19	2.29	2.52	6.72	1.01	1.03
16	12,108	6.45	69.24	74.76	23.38	25.24	2.81	3.03	4.57	.42	.43
17	6,843	6.59	69.74	74.63	23.71	25.37	1.39	1.49	5.16	.65	.66
18	8,474	4.66	69.37	74.62	23.60	25.38	1.71	1.84	5.32	.67	.68
19	10,739	3.87	69.44	75.06	23.07	24.94	2.36	2.55	5.13	.66	.68
20	6,054	5.24	69.75	74.98	23.28	25.02	1.79	1.92	5.18	.68	.69
21	6,114	6.25	72.62	82.53	15.37	17.47	2.61	2.97	9.40	.79	.81

[a] The "combustible" factor in all columns of this table marked thus (*) is obtained by subtracting from the total weight of dry fuel fired the weight of ash therein as figured from the chemical analysis and also subtracting the weight of the combustible in the refuse, the latter combustible being calculated from the total weight of refuse and its analysis; the composition of the refuse combustible is loosely considered to be the same as that of the "combustible" of the dry fuel.

TABLE 16.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. "Biddle," Dec. 6, 1907, to Jan. 27, 1908*—Continued.

Test No.	Ultimate analysis, dry basis (per cent).					Carbon in refuse (per cent).	Earthy matter in refuse, including moisture (per cent).	Fired per hour (pounds).			Heat value per pound (B.t.u.).	
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.			Dry fuel. For grate.	Dry fuel. Per square foot of grate.	"Combustible" (*).	Dry fuel.	"Combustible."
1	33 (37)	34 (38)	35 (39)	36(40)	37(42)	38 (44)	39 (45)	40 (46)	41 (48)	42 (47)	43 (50)	44 (51)
1	82.58	4.55	5.10	1.45	5.55	54.95	45.05	1,718	29.62	1,474	14,845	15,715
2	83.39	4.49	3.42	1.38	6.60	40.99	59.01	2,389	41.20	2,152	14,591	15,622
3	84.39	4.65	4.63	1.39	4.28	50.22	49.78	1,139	19.64	1,039	15,098	15,773
4	84.98	4.57	3.11	1.50	4.92	41.29	58.71	1,225	21.12	1,118	14,927	15,699
5	84.23	4.61	3.93	1.39	4.94	50.73	49.27	1,676	28.90	1,542	14,879	15,652
6	82.64	4.39	5.87	1.18	5.04	40.44	59.56	2,627	45.29	2,433	14,933	15,726
7	84.38	4.44	3.19	1.44	5.84	54.63	45.37	1,746	30.10	1,567	14,769	15,685
8	83.61	4.29	3.55	1.39	6.16	43.70	56.30	1,177	20.29	1,044	14,720	15,686
9	83.77	4.23	2.86	1.48	6.91	39.00	61.00	2,634	45.41	2,394	14,702	15,793
10	83.21	4.54	4.16	1.41	5.89	37.56	62.44	1,838	31.68	1,684	14,980	15,918
11	84.53	4.37	2.80	1.40	6.08	49.14	50.86	2,625	45.26	2,388	14,816	15,775
12	83.06	4.49	4.32	1.37	5.98	38.61	61.39	1,184	20.41	1,074	14,794	15,735
13	83.69	4.42	3.60	1.45	5.96	53.02	46.98	3,760	64.83	3,458	14,805	15,743
14	80.95	4.73	4.52	1.49	7.68	42.16	57.84	1,226	21.14	1,095	14,368	15,563
15	82.00	4.73	3.86	1.50	6.88	39.88	60.12	1,739	29.98	1,578	14,564	15,640
16	83.95	4.82	4.57	1.53	4.70	33.40	66.60	3,023	52.12	2,816	14,884	15,618
17	84.12	4.72	3.85	1.42	5.23	27.26	72.74	1,389	23.95	1,291	14,949	15,774
18	83.75	4.76	4.03	1.37	5.41	27.26	72.74	2,162	37.28	2,018	14,803	15,650
19	84.05	4.72	3.92	1.38	5.25	47.03	52.97	3,002	51.76	2,789	14,906	15,732
20	84.13	4.65	3.77	1.49	5.27	44.12	55.88	4,146	71.48	3,832	14,796	15,619
21	79.18	4.36	4.69	1.31	9.65	30.43	69.57	1,686	29.07	1,491	14,180	15,695

Test No.	Steam.		Water fed to boiler (pounds).						Evaporation.	
	Moisture in (per cent).	Quality of.	Total.	Equivalent evaporated from and at 212°. Total.	Equivalent evaporated from and at 212°. Per hour.	Equivalent evaporated from and at 212°. Into dry steam.	Actually evaporated.[a] Total.	Actually evaporated.[a] Per hour.	Apparent per pound of coal as fired.	Factor of.
1	45 (54)	46 (56)	47 (57)	48 (58)	49 (63)	50 (61)	51 (59)	52 (62)	53 (68)	54 (60)
1	1.10	99.22	68,579	83,899	15,873	83,333	68,044	12,961	7.48	1.2247
2	1.13	99.20	58,940	72,184	21,503	71,606	58,468	17,558	7.30	1.2247
3	1.67	98.81	64,985	79,470	10,983	78,525	64,212	8,981	7.85	1.2229
4	1.73	98.77	59,102	72,335	11,468	71,445	58,375	9,370	7.61	1.2239
5	1.55	98.90	57,483	70,359	13,644	69,586	56,851	11,147	6.62	1.2240
6	1.61	98.86	68,569	83,874	20,575	82,917	67,787	16,821	6.36	1.2232
7	1.57	98.89	59,121	72,400	15,233	71,596	58,465	12,439	7.06	1.2246
8	1.61	98.86	57,811	70,784	11,702	69,977	57,152	9,557	7.98	1.2244
9	1.73	98.77	75,855	92,884	22,652	91,742	74,922	18,499	6.93	1.2245
10	1.90	98.65	55,607	68,085	16,918	67,166	54,856	13,818	7.52	1.2244
11	2.35	98.33	78,415	96,090	23,158	94,484	77,105	18,898	7.19	1.2254
12	1.85	98.69	60,065	73,646	11,954	72,681	59,278	9,750	8.21	1.2261
13	2.42	98.29	57,697	70,708	29,324	69,498	56,710	23,928	6.36	1.2255
14	2.16	98.47	64,975	79,640	11,567	78,422	63,981	9,437	7.62	1.2257
15	1.98	98.60	58,624	71,850	15,334	70,843	57,803	12,511	7.13	1.2256
16	2.25	98.41	88,247	108,147	24,750	106,427	86,844	20,196	6.60	1.2255
17	1.68	98.81	54,875	67,315	12,550	66,514	54,222	10,231	7.35	1.2267
18	1.71	98.83	65,493	80,347	18,906	79,407	64,727	15,411	7.09	1.2268
19	2.32	98.40	82,503	100,992	25,812	99,376	81,183	21,086	6.97	1.2241
20	2.51	98.23	41,270	50,741	31,547	49,844	40,540	25,658	6.19	1.2295
21	2.56	98.19	51,075	62,710	15,018	61,575	50,151	12,232	7.20	1.2278

[a] Corrected for quality of steam.

TABLE 16.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. "Biddle," Dec. 6, 1907, to Jan. 27, 1908*—Continued.

Test No.	Equivalent evaporation per pound of—			Horsepower developed.		Efficiency of the boiler, etc.		Per cent smoke.	Average thickness of fuel bed (inches).[b]
	Fuel as fired.	Dry fuel fired.	"Combustible" (*).	In boiler.	Per cent of builders' rated.[a]	(*)	Including grate.		
1	55 (69)	56 (70)	57 (71)	58 (65)	59 (67)	60 (72)	61 (73)	62 (77)	63 (81)
1	9.09	9.24	10.77	460.1	166	66.17	60.11	64.50	12
2	8.87	9.00	9.99	623.3	225	61.75	59.57	60.89	14
3	9.48	9.64	10.57	318.3	115	64.71	61.66	58.75	8
4	9.19	9.36	10.25	332.4	120	63.05	60.55	69.54	16
5	8.02	8.14	8.85	395.5	143	54.60	52.83	70.54	16
6	7.69	7.83	8.46	596.4	215	51.95	50.64	67.20	6
7	8.56	8.72	9.72	441.5	159	59.84	57.02	29.88	10
8	9.65	9.94	11.21	339.2	122	69.01	65.21	35.87	8
9	8.39	8.61	9.46	656.6	236	57.85	56.56	30.57	16
10	9.09	9.20	10.05	490.4	177	60.97	59.31	48.75	8
11	8.66	8.82	9.70	671.8	242	59.38	57.49	37.86	10
12	9.94	10.10	11.13	346.5	125	68.31	65.93	31.02	8
13	7.66	7.80	8.48	850.0	306	52.02	50.88	37.81	10–12
14	9.19	9.43	10.57	335.3	121	65.58	63.38	47.41	8
15	8.61	8.82	9.72	444.5	160	60.02	58.48	48.84	10
16	7.96	8.19	8.79	717.4	254	54.35	53.14	43.03	12
17	8.91	9.04	9.72	363.8	131	59.51	58.39	46.14	8–9
18	8.59	8.74	9.37	548.1	197	57.82	57.02	49.28	8–9
19	8.40	8.60	9.25	748.2	270	56.78	55.72	21.71	10–12
20	7.47	7.61	8.23	914.4	330	50.89	49.67	51.33	12
21	8.67	8.91	10.07	435.3	157	61.96	60.68	31.86	10

Test No.	Analysis of dry flue gases (per cent).				Pounds of dry flue gases per pound of "combustible."	Sparks ejected (pounds).		Heat value of 1 pound of "combustible" (B. t. u.).	Heat balance.[c]			
									Heat absorbed by boiler (1).		Heat lost in dry flue gases (4).	
	CO_2.	O_2.	CO.	N_2.		During test.	Per hour.		B. t. u.	Pr. ct.	B. t. u.	Pr. ct.
1	64 (84)	65 (85)	66 (86)	67 (88)	68	69	70	71	72	73	74	75
1	7.90	10.53	0.12	81.45	26.97	200	38.2	15,717	10,401	66.17	4,342	27.63
2	9.06	9.60	.08	81.26	24.28	412	123.7	15,622	9,647	61.75	3,933	25.18
3	9.27	9.44	.03	81.26	23.59	125	17.0	15,773	10,207	64.71	3,199	20.28
4	10.52	7.30	.14	82.04	20.94	35	5.6	15,699	9,898	63.05	3,087	19.66
5	11.70	5.03	.00	83.27	18.98	265	52.0	15,652	8,546	54.60	3,371	21.54
6	12.41	4.64	.00	82.95	17.63	230	57.0	15,726	8,170	51.95	3,600	22.89
7	9.86	8.22	.00	81.92	22.65	......	....	15,685	9,387	59.84	3,289	20.97
8	9.16	9.30	.00	81.54	24.18	......	....	15,686	10,825	69.01	3,111	19.83
9	10.27	7.95	.00	81.78	21.88	......	....	15,793	9,136	57.85	3,497	22.14
10	10.37	7.65	.02	81.96	21.25	......	....	15,918	9,705	60.97	3,233	20.31
11	10.40	7.40	.00	82.20	21.60	400	97.0	15,775	9,367	59.38	3,841	24.35
12	9.50	9.13	.00	81.37	23.15	80	13.2	15,735	10,748	68.31	2,879	18.30
13	11.86	5.53	.00	82.61	18.83	380	160.0	15,743	8,189	52.02	3,426	21.76
14	10.00	8.40	.00	81.60	21.87	180	26.5	15,563	10,207	65.58	2,714	17.44
15	10.97	7.00	.00	82.03	20.09	210	45.5	15,640	9,387	60.02	2,951	18.87
16	9.85	8.07	.00	82.08	22.28	410	95.0	15,618	8,489	54.35	3,529	22.60
17	9.58	8.20	.00	82.22	23.06	60	11.3	15,774	9,387	59.51	3,121	19.79
18	9.60	8.10	.00	82.30	22.95	240	57.0	15,650	9,049	57.82	3,503	22.38
19	9.36	8.12	.00	82.52	....	440	114.0	15,732	8,933	56.78	3,906	24.83
20	10.30	6.85	.00	82.85	21.50	380	240.0	15,619	7,948	50.89	3,988	25.53
21	10.40	7.47	.00	82.13	21.04	180	44.0	15,695	9,725	61.96	2,767	17.62

[a] Arbitrarily rated, counting 10 square feet of heating surface to a boiler horsepower.
[b] Method of firing, side alternate.
[c] Heat balance items (designated by numbers in parentheses under this heading) are explained in U. S. Geological Survey Bulletin No. 325, p. 153.

TABLE 16.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. "Biddle," Dec. 6, 1907, to Jan. 27, 1908*—Continued.

Test No.	Heat balance.[a]										Smoke and flame showing above stack.		
	Loss due to moisture—				Loss due to incomplete combustion of carbon in CO (5).		Loss in sparks.		Loss in escaping hydrocarbons, radiation, and unaccounted for (6).		F.	S.	Per cent.[b]
	In fuel (2).		Formed by burning hydrogen (3).										
	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.			
1	76	77	78	79	80	81	82	83	84	85	86	87	88
1	24	0.15	591	3.76	133	0.85	307	1.96	−81	−0.52	0	608	0.0
2	22	.14	592	3.80	79	.50	648	4.15	703	4.50	7	360	2.0
3	23	.15	571	3.62	29	.18	186	1.18	1,558	9.88	1	720	.1
4	25	.16	578	3.68	119	.76	51	.32	1,941	12.37	6	660	.9
5	22	.14	611	3.90	0	....	348	2.22	2,751	17.60	65	480	13.5
6	28	.18	602	3.83	0	....	248	1.58	3,078	19.57	214	508	42.8
7	28	.18	569	3.63	0	....	....	....	2,412	15.38	13	480	2.7
8	42	.27	536	3.42	0	....	....	....	1,172	7.47	0	664	.0
9	37	.23	557	3.53	0	....	....	....	2,566	16.25	6	452	1.3
10	18	.11	585	3.68	17	.11	....	....	2,360	14.82	19	480	4.0
11	28	.18	587	3.72	0	....	389	2.46	1,563	9.91	24	420	5.7
12	22	.14	555	3.52	0	....	113	.72	1,418	9.01	0	686	.0
13	27	.17	598	3.80	0	....	470	2.99	3,033	19.26	59	292	20.2
14	37	.24	594	3.82	0	....	266	1.71	1,745	11.21	1	764	.1
15	34	.22	613	3.92	0	....	295	1.89	2,360	15.08	7	500	1.4
16	41	.26	621	3.98	0	....	369	2.36	2,569	16.45	9	456	2.0
17	19	.12	587	3.72	0	....	87	.55	2,573	16.31	16	600	2.7
18	25	.16	608	3.89	0	....	314	2.01	2,151	13.74	8	420	1.9
19	35	.22	617	3.92	0	....	443	2.82	1,798	11.43	13	420	3.1
20	27	.17	629	4.03	0	....	744	4.76	2,283	14.62	14	240	5.8
21	39	.25	569	3.63	0	....	323	2.06	2,474	14.48	1	420	.2

[a] Heat balance items (designated by numbers in parentheses under this heading) are explained in U. S. Geological Survey Bulletin No. 325, p. 153.

[b] Per cent $=\frac{\text{Flame readings}}{\text{Smoke readings}}\times 100$.

The following conclusions apply only to the tests of New River run-of-mine coals when burned under a boiler of the Normand type and on vessels of the torpedo-boat class:

There is little or no gain in efficiency in burning briquets of either size.

Both large and small briquets make as much (or more) smoke as run-of-mine coal.

There seems to be more flaming in the stack with briquets than with run-of-mine coal.

About the same amount of sparks are emitted from the stack whether briquetted or run-of-mine coal is burned.

When burning briquets the fire does not need to be disturbed; with coal the fuel bed has to be broken up, generally after each firing.

A somewhat higher boiler capacity can be obtained with briquets than with run-of-mine coal.

Steam can be raised more quickly with briquets than with run-of-mine coal.

Run-of-mine coal is transferred much more readily than briquets from the coal bunker to the fireroom.

With briquets the capacity of a coal bunker is reduced by 23 to 27 per cent.

TESTS OF RUN-OF-MINE AND BRIQUETTED COAL IN A LOCOMOTIVE BOILER.

In connection with the fuel-testing work at Norfolk comparative steaming tests were made on a locomotive boiler with run-of-mine coal and the same coal formed into briquets of two sizes. These tests were undertaken to add cumulative evidence to work done at other places. They were made possible through the courtesy of the Seaboard Air Line Railway Co. in supplying both the locomotive and the coal used. During the trials the locomotive stood on a side track in the shop yards of the railway company at Portsmouth, Va. No running tests were made. These tests were published in United States Geological Survey Bulletin No. 412, and reprinted in Bureau of Mines Bulletin 34.

The primary object of the tests was to study the relative performance of the two types of briquets and of the coal, with reference to efficiency, tendency to smoke, and the ease with which steam could be kept up, when each of the three varieties of fuel was burned at several rates of combustion. One object kept especially in mind was the finding of ways for working locomotive boilers harder.

All the coal was run-of-mine from the Turkey Gap mine, working the Pocohontas No. 3 bed at Ennis, McDowell County, W. Va. Part of it went to the briquetting section of the fuel-testing plant at Norfolk, where it was made into two sizes of briquets.

The smaller of these two sizes was circular in horizontal cross section, 3¼ inches in diameter. Its vertical cross section was nearly oval, 2¾ inches high at the center and 1¼ inches near the circumference. The larger size was rectangular in either cross section, its dimensions being 3 by 4¼ by 6¾ inches. The small briquets were compressed at about 1,000 pounds and the large ones at about 2,500 pounds per square inch. The pitch used was approximately the same in kind and percentage.[a]

The locomotive used in these tests was of the 10-wheel, freight type, built in 1906. The principal dimensions of its furnace and boiler are given in Table 17.

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[a] For a detailed description of methods of manufacture and physical tests of briquets see Briquetting Tests at Norfolk, Va., Wright, C. L., U. S. Geological Survey Bulletin No. 385, 1909. Reprinted as Bureau of Mines Bulletin 30.

TABLE 17.—*Principal dimensions of furnace and boiler.*

Furnace:		
Length	inches	108
Width near grate	do	41
Width at widest place	do	55
Height	do	55
Rocking, finger-type grate:		
Length	do	104
Width	do	41
Area	square feet	29.65
Ratio to heating surface		1 to 87.2
Approximate air space	per cent	30
Boiler:		
Diameter of shell	inches	68.5
Waist diameter	do	72
Number of tubes		328
Inside diameter of tubes	inches	2
Length of tubes	feet	14½
Heating surface:		
Of fire box	square feet	167.5
Of tubes	do	2,416.5
Total	do	2,584
Approximate minimum cross sectional area of gas passage	square feet	1

The furnace was equipped with a fire-brick arch supported by four 2½-inch water tubes. The position and construction of the arch are shown in figure 82.

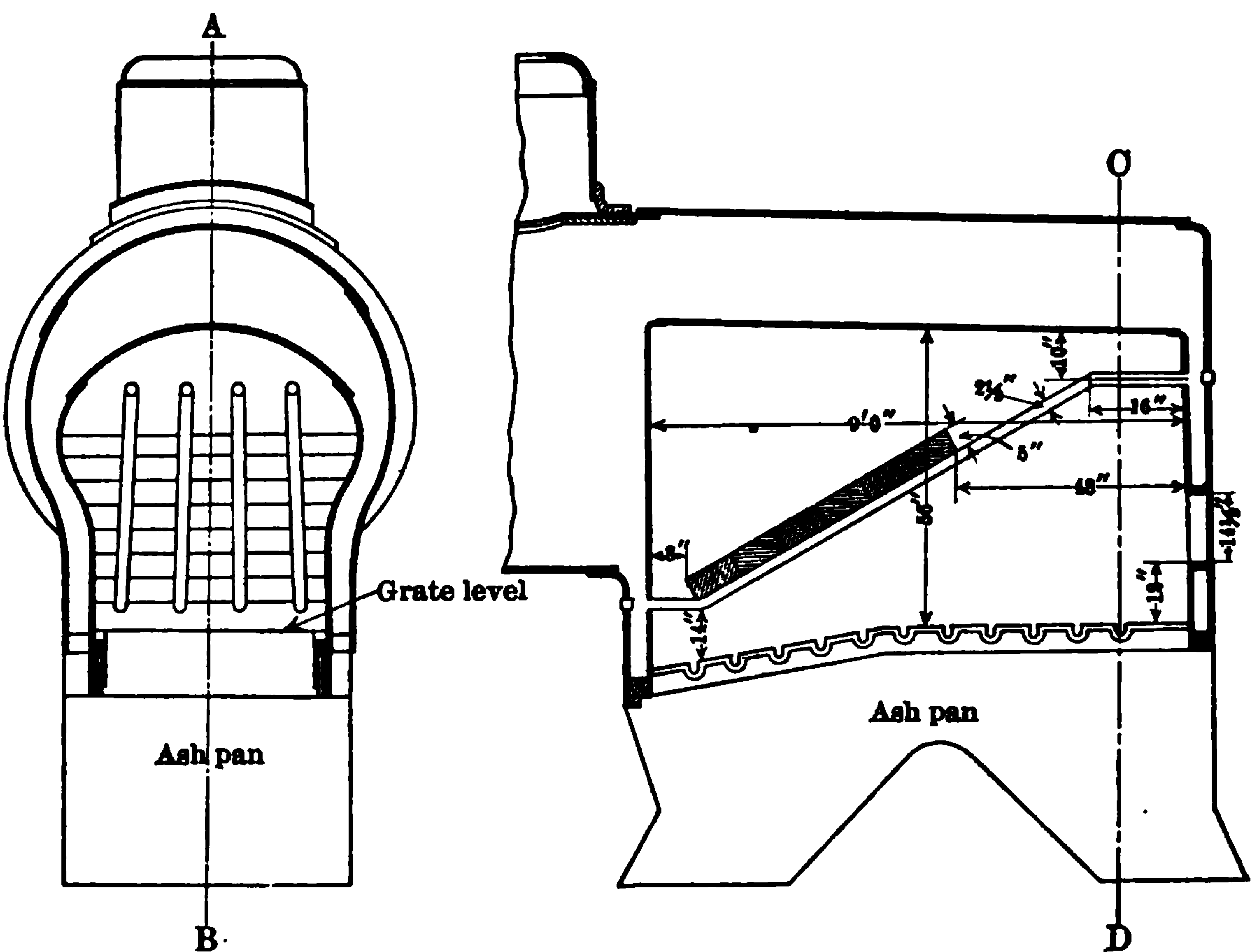

FIGURE 82.—Arch in locomotive furnace.

Figure 83 shows the internal arrangement of the smoke box. The partition CDE, and the spark screen HJK, separates it into three chambers, which are designated *a*, *b*, and *c*. Chamber *a* receives the gases as they leave the boiler tubes. From chamber *a* the gases flow through the contracted passage between G and L into chamber *b*. The sparks are deflected upward from their straight course by the plate LM and thrown against the screen HJK; they are partly broken by impact against the deflecting plate and the screen, and the small pieces pass through the latter and out through the stack. Larger pieces are deflected back and fall down toward the apron, most of them into the high-velocity current of gas which again hurls

them against the deflecting plate and the screen; eventually practically all of the sparks pass through the stack. The purpose of all these fittings in the smoke box is to reduce the size of the sparks before ejectment so as to make them less noticeable and less dangerous to fields, buildings, etc.

Figure 83 shows also the location of draft-gage connections, flue-gas sampler, and a thermometer for making approximate measurements of flue-gas temperature. The flue-gas sampler was made of $\frac{3}{8}$-inch pipe, having the free end plugged and $\frac{1}{16}$-inch holes drilled on both sides in staggered rows. It extended nearly across the smoke box.

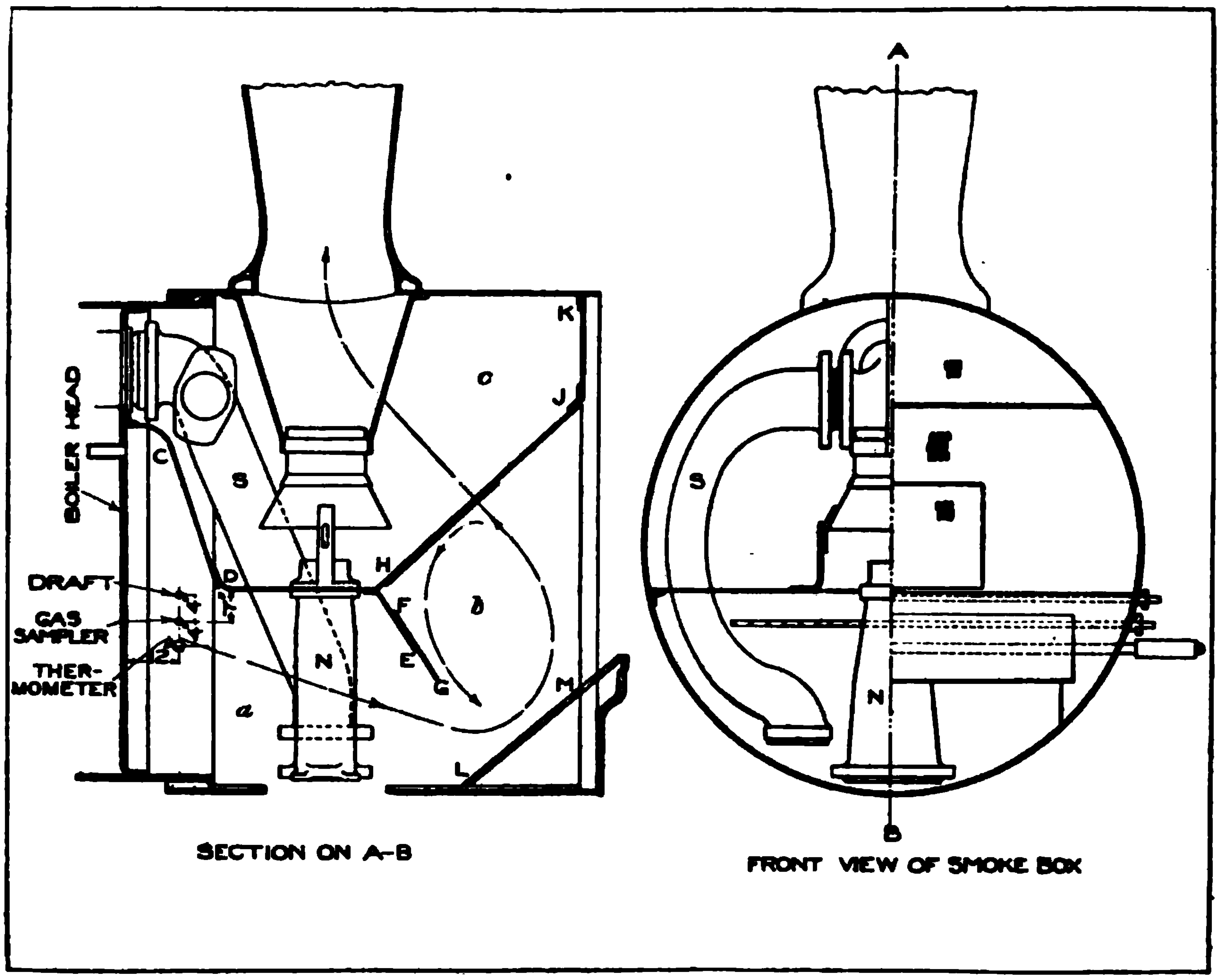

FIGURE 83.—Locomotive smoke box.

The draft pipe was of $\frac{1}{4}$-inch pipe, with no holes in the sides, and had its open end situated at the center of the smoke box. The bulb of the thermometer was placed close to the end of this pipe.

Figure 84 shows, attached to the stack, the spark catcher especially designed and constructed for these tests. Its object was to collect the sparks from a sector of the exit end of the stack, the sector constituting one-tenth of the total exit area so that the total weight of sparks leaving the stack was approximately ten times the weight collected in the receptacle.

A modification of the "alternate method" was used in starting and closing tests. Fire was kindled with wood on a clean grate and built up rapidly with coal. As soon as the steam pressure had

risen to 200 pounds the fire was leveled and the test started. This preparatory firing took one to two hours and required the burning of 300 to 500 pounds of coal. Closing conditions of the test were made as nearly as possible the same as those of starting.

After the close of the test the fire was burned down entirely, the clinkers pulled out of the fire door, weighed, and charged to the test. It was impracticable to clean the fire before the close of the test, because the lower edge of the fire door was 14 inches above the grate. Immediately before starting each test the ash pan was cleaned. After

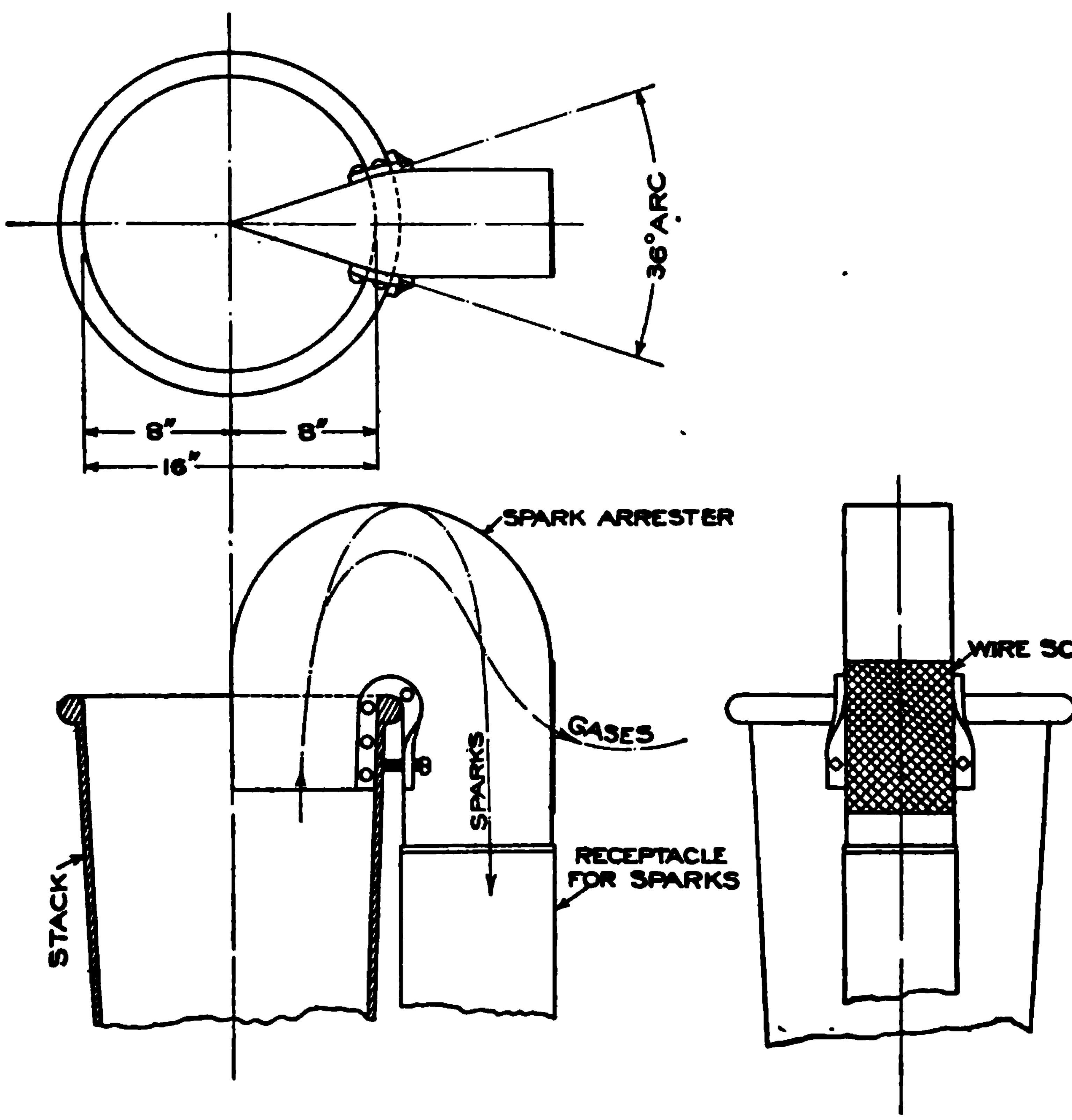

FIGURE 84.—Spark catcher for locomotive and its attachment to stack.

closing and removing the clinker from the grate all the ash was taken from the ash pan, weighed and charged to the test.

In all, 14 tests were made; 6 on run-of-mine coal, 4 on large briquets, and 4 on small briquets. The tests were made at various rates of combustion, the lowest being 18 pounds of dry fuel per hour per square foot of grate surface when burning run-of-mine coal, and the highest being about 110 pounds of dry fuel when burning small briquets.

The recorded observations made during the tests and the results calculated therefrom are given in Table 18.

TABLE 18.—*Summary of observed data and calculated items of 14 tests made with a locomotive boiler, Feb. 7–27, 1908.*[a]

Test No.	Form and condition of fuel.	Date of trial.	Duration (hours).	Average pressures. Barometer (inches of mercury).	Average pressures. Steam[c] (pounds per sq. in.).	"Draft"[b] below atmosphere (inches of water). Near nozzle.	"Draft" Over fuel bed.	"Draft" Over furnace arch.	"Draft" Leaving boiler tubes.	Clinker in ash and refuse (per cent).
1	2	3 (1)	4 (2)	5 (11)	6 (11.1)	7	8	9	10	11 (29)
1...	Run of mine......	Feb. 7	6.08	30.34	171	0.77	0.39	0.48	0.61	52.7
2...	......do.[d]...........	Feb. 8	5.08	30.51	172	2.30	1.05	1.01	1.86	52.7
3...	......do.............	Feb. 10	6.17	30.68	149	2.27	.87	1.12	1.86	45.0
4...	......do.............	Feb. 11	7.00	30.50	159	.59	.33	.41	.53	52.7
5...	Large briquets....	Feb. 12	5.28	30.53	171	1.25	.57	.70	1.00	46.0
6...	......do.............	Feb. 13	4.50	30.31	162	2.63	1.08	1.37	1.96	56.0
7...	......do.............	Feb. 14	4.45	29.97	186	5.48	1.96	2.54	3.69	28.3
8...	......do.............	Feb. 17	3.60	30.06	182	7.70	....	3.01	4.10	45.8
9...	Run of mine[e]......	Feb. 18	3.92	30.36	168	7.36	....	2.65	4.54	19.7
10...	Small briquets[f]...	Feb. 19	4.07	29.80	167	2.11	....	.56	1.59	21.6
11...	......do.............	Feb. 20	3.07	30.03	182	8.10	....	2.73	5.48	22.2
12...	......do.............	Feb. 21	3.48	30.16	171	5.07	....	1.95	3.69	24.5
13...	Run of mine......	Feb. 26	4.18	29.67	168	5.50	....	2.41	3.89	21.6
14...	Small briquets[g]...	Feb. 27	2.02	29.78	150	11.80	....	3.10	8.74	21.8

Test No.	Average temperatures (°F.) of—				Fuel (total weights in pounds). As fired.	Fuel. Dry.	Fuel. Ash and refuse.	"Combustible*"[h] consumed (lbs.).	Fired per hour (pounds). Dry fuel. Per grate.	Dry fuel. Per sq. ft. of grate.	"Combustible*."[h] Per grate.	"Combustible*." (i)
				l)	16 (25)	17 (27)	18 (28)	19 (30)	20 (46)	21 (48)	22 (47)	23 (49)
1....	45	375	55	580	4,600	4,432	210	3,965	729	24.60	656	0.253
2....	40	376	63	590	5,500	5,260	425	4,770	1,035	34.63	955	.368
3....	39	365	49	596	7,200	6,856	472	6,208	1,112	37.53	1,026	.395
4....	37	370	48	497	3,986	3,834	224	3,400	548	18.47	494	.187
5....	44	375	51	560	4,367	4,217	272	3,849	799	26.95	729	.282
6....	56	371	51	612	6,000	5,749	231	5,247	1,277	43.10	1,166	.451
7....	63	375	50	663	7,420	7,078	465	6,451	1,590	53.62	1,450	.561
8....	56	380	51	697	9,030	8,638	522	7,882	2,274	76.70	2,074	.808
9....	36	374	49	666	9,070	8,469	617	7,665	2,160	72.85	1,960	.759
10....	55	374	49	595	4,800	4,683	474	4,242	1,151	38.80	1,024	.403
11....	41	380	48	804	7,500	7,271	450	6,618	2,369	79.90	2,155	.834
12....	41	375	46	684	6,300	6,156	391	5,680	1,770	59.69	1,632	.631
13....	51	374	48	679	7,800	7,318	651	6,617	1,750	59.02	1,583	.613
14....	40	365	46	910	6,800	6,489	417	5,701	3,213	108.30	2,822	1.092

[a] Code numbers (in parentheses at the top of certain columns) refer to corresponding items described in Bulletin U. S. Geological Survey No. 325, pp. 151–153. See also Professional Paper U. S. Geol. Survey No. 48, pt. 2. These are the item numbers in the code for boiler tests as recommended by the American Society of Mechanical Engineers.

[b] The word "draft" is placed in quotation marks because it is misused when applied to the moving of gases or to the pressure difference which causes them to move.

[c] Above atmosphere.

[d] Wet, much slack.

[e] Wet, mostly slack.

[f] 10 per cent crumbled.

[g] 30 per cent crumbled.

[h] The "combustible" factor in all columns of this table marked thus (*) is obtained by subtracting from the total weight of dry fuel fired the weight of ash therein, as figured from the chemical analysis, and further subtracting weight of the combustible in the refuse, the latter combustible being calculated from the total weight of refuse and its analysis; the composition of the refuse combustible is loosely considered to be the same as that of the "combustible" of the dry fuel.

[i] Per square foot of water-heating surface.

TABLE 18.—*Summary of observed data and calculated items of 14 tests made with a locomotive boiler, Feb. 7-27, 1908*—Continued.

Test No.	Ash and refuse in dry fuel (per cent).	Proximate analysis (per cent). Fixed carbon. In moist coal.	Fixed carbon. In "combustible."	Volatile matter. In moist coal.	Volatile matter. In "combustible."	Moisture. In fuel as fired.	Moisture. ([b])	Ash. Moist basis.	Ash. Dry basis.	Sulphur.[a] Moist basis.	Sulphur.[a] Dry basis.
1	24 (31)	25 (32)	26	27 (33)	28	29 (34)	30	31	32 (42)	33	34 (41)
1	8.57	73.35	83.13	14.97	16.87	3.66	4.13	7.62	7.91	0.45	0.47
2	7.82	73.67	83.49	14.56	16.51	4.35	4.93	7.42	7.76	.49	.51
3	....	74.24	84.46	13.66	15.54	4.76	5.42	7.34	7.71	.36	.38
4	....	73.25	84.48	13.46	15.52	3.78	4.36	9.51	9.88	.38	.39
5	....	73.13	81.67	16.41	18.33	3.43	3.83	7.03	7.28	.52	.54
6	....	73.12	82.35	15.67	17.65	4.25	4.79	6.96	7.27	.50	.50
7	5.62	73.47	82.85	15.21	17.15	4.63	5.22	6.69	7.01	.51	.53
8	6.00	72.12	81.04	16.86	18.96	4.31	4.85	6.71	7.01	.42	.44
9	6.03	71.24	82.58	15.01	17.42	6.64	7.70	7.11	7.62	.54	.58
10	9.83	74.41	81.07	17.37	18.93	2.42	2.53	5.80	5.94	.39	.40
11	6.14	72.66	80.87	17.18	19.13	3.01	3.45	7.15	7.37	.47	.48
12	....	73.82	80.43	17.96	19.57	2.24	2.44	5.98	6.12	.51	.52
13	....	73.17	83.91	14.03	16.09	6.18	7.09	6.62	7.06	.52	.55
14	6.32	69.04	80.30	16.93	19.70	4.56	5.31	9.47	9.92	.58	.61

Test No.	Ultimate analysis, dry basis (per cent). Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Carbon in refuse.	Earthy matter in refuse, including moisture.	Heat value per pound (B. t. u.). Dry fuel.	Heat value per pound (B. t. u.). "Combustible."	Steam (per cent). Moisture in.	Steam (per cent). Quality of.
1	35 (37)	36 (38)	37 (39)	38 (40)	39 (44)	40	41 (50)	42 (51)	43 (54)	44 (56)
1	83.15	4.29	3.14	1.04	46.28	53.72	14,463	15,705	0.5	0.996
2	84.30	4.23	2.21	.99	20.40	79.60	14,494	15,720	.7	.995
3	82.73	4.11	4.02	1.05	25.14	74.86	14,553	15,782	.3	.998
4	81.38	4.13	3.19	1.03	17.42	83.58	14,245	15,816	.5	.996
5	84.84	4.31	2.05	.98	22.31	77.69	14,693	15,844	1.4	.990
6	83.66	4.16	3.41	1.00	34.51	65.49	14,789	15,945	.9	.992
7	83.98	4.22	3.32	.94	27.68	72.32	14,702	15,815	1.0	.993
8	84.19	4.18	3.07	1.11	29.42	70.58	14,753	15,868	1.0	.993
9	84.12	4.18	2.54	.96	26.91	73.09	14,508	15,688	.8	.994
10	84.48	4.05	4.03	1.10	34.69	65.31	14,897	15,838	1.0	.993
11	83.19	4.16	3.99	.81	26.57	73.43	14,742	15,743	1.0	.998
12	84.62	4.42	3.31	1.01	26.08	73.92	14,936	15,915	.7	.995
13	84.73	4.23	2.45	.98	28.31	71.69	14,571	15,680	.9	.993
14	82.21	4.25	2.03	.98	34.92	65.08	14,292	15,871	1.4	.988

[a] Separately determined.

[b] Accompanying 100 per cent of "combustible."

TABLE 18.—*Summary of observed data and circulated items of 14 tests made with a locomotive boiler, Feb. 7-27, 1908*—Continued.

Test No.	Water fed to boiler (pounds).							Evaporation.		Equivalent evaporation per pound of—		
	Total.	Equivalent evaporated from and at 212°.				Actually evaporated.[a]		([c])	Factor of.	Fuel as fired.	Dry fuel.	"Combustible*."[d]
		Total.	Per hour.	([b])	Into dry steam.	Total.	Per hour.					
1	45 (57)	46 (58)	47 (63)	48	49 (61)	50 (59)	51 (62)	52 (68)	53 (60)	54 (69)	55 (70)	56 (71)
1.....	43,655	52,998	8,681	3.36	52,786	43,480	7,151	9.49	1.214	11.47	11.91	13.24
2.....	50,064	60,452	11,840	4.58	60,125	49,814	9,806	9.10	1.207	10.94	11.43	12.61
3.....	61,028	74,332	12,023	4.65	74,183	60,906	9,871	8.48	1.218	10.30	10.82	11.95
4.....	36,333	44,363	6,312	2.442	44,186	36,188	5,170	9.11	1.221	11.08	11.52	13.00
5.....	40,070	48,885	8,977	3.474	47,397	39,669	7,513	9.18	1.220	10.85	11.24	12.31
6.....	52,713	64,204	14,153	5.48	63,690	52,291	11,620	8.79	1.218	10.62	11.08	12.14
7.....	63,688	77,890	17,381	6.726	77,345	63,242	14,211	8.58	1.223	10.42	10.93	11.99
8.....	72,558	88,593	23,151	8.966	87,978	72,050	18,960	8.03	1.221	9.74	10.18	11.03
9.....	60,283	73,704	18,689	7.233	73,262	59,921	15,285	6.64	1.223	8.08	8.65	9.53
10.....	43,305	52,832	12,889	4.99	52,462	43,002	10,565	9.02	1.221	10.93	11.20	12.36
11.....	62,998	77,109	24,941	9.64	76,569	62,557	20,377	8.40	1.224	10.21	10.52	11.57
12.....	53,956	66,096	18,898	7.313	65,766	53,686	15,429	8.56	1.225	10.44	10.68	11.58
13.....	59,484	72,689	17,268	6.682	72,180	59,068	14,131	7.63	1.222	9.25	9.86	10.91
14.....	47,730	58,326	28,528	11.040	57,627	47,157	23,345	7.02	1.222	8.48	8.88	10.11

Test No.	Horsepower developed.		Efficiency of the boiler, etc.		Average thickness of fuel bed (inches).[g]	Average time intervals (minutes) between—		Analysis of dry flue gases (per cent).			
	In boiler.	Per cent of rated.[e]	(*)[f]	Including grate.		Firings.	Leveling and breaking up.	CO_2.	O_2.	CO.	N_2.
1	57 (65)	58 (67)	59 (72)	60 (73)	61 (81)	62 (82)	63 (83)	64 (84)	65 (85)	66 (86)	67 (88)
1......	251.7	97.4	81.44	79.48	8	3-4	16	11.45	6.92	....	81.63
2......	343.2	132.8	77.48	76.18	10-12	3	10	11.96	7.00	0.23	80.81
3......	348.5	134.4	73.14	71.79	12	3	12	11.46	7.49	.10	80.95
4......	183.0	70.8	79.39	78.12	6	4-5	40	11.10	7.84	.23	80.83
5......	260.0	100.6	75.00	73.90	14-16	3	40	11.96	7.07	.14	80.83
6......	410.2	159.0	73.50	72.37	14-16	3	([h])	12.45	5.87	.22	81.46
7......	503.8	195.0	73.26	71.81	18	3	80	11.50	7.08	.17	81.25
8......	671.0	259.5	67.16	66.67	16	3	([h])	12.05	6.93	.15	80.87
9......	541.1	209.3	58.69	57.61	16	3	20	10.16	8.49	.13	81.22
10......	373.6	144.5	75.39	72.62	6-8	....	([h])	13.87	4.75	.25	81.13
11......	722.9	279.7	70.99	68.94	12	3	([h])	13.57	4.49	.03	81.91
12......	547.7	211.9	70.29	69.08	8	3	([h])	11.78	6.74	.30	81.18
13......	500.5	193.7	67.21	65.36	14-16	3	16	12.20	6.94	.05	80.81
14......	827.0	320.0	61.56	60.02	16-18	([i])	([h])	11.15	7.52	.20	81.13

[a] Corrected for quality of steam.
[b] Per hour per square foot of water-heating surface.
[c] Apparent per pound of coal as fired.
[d] Figured from chemical analyses of ash and coal.
[e] Arbitrarily rated by authors, counting 10 square feet of heating surface to a boiler horsepower
[f] Figured from chemical analyses of ash and coal.
[g] Method of firing, spreading.
[h] Fire not disturbed.
[i] Firing continuous.

TABLE 18.—*Summary of observed data and calculated items of 14 tests made with a locomotive boiler, Feb. 7-27, 1908*—Continued.

Test No.	Per cent smoke.	Sparks (pounds).			Heat balance.[a]					
		Total collected.	Ejected.		Heat value of 1 pound of "combustible."		Heat absorbed by boiler (1).		Loss in sparks.	
			During test.	Per hour.	B. t. u.	Per cent.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.
1	68 (77)	69	70	71	72	73	74	75	76	77
1	0	1	10	1.65	15,705	100	12,790	81.44	....	....
2	15.4	7	70	13.77	15,720	100	12,181	77.48	137.1	0.88
3	19.4	21	210	34	15,782	100	11,544	73.14	215	1.36
4	24	No sparks collected.			15,818	100	12,558	79.39	....	....
5	10	2	20	3.79	15,846	100	11,891	75.60	41	.26
6	10	9	90	20	15,955	100	11,727	73.50	161	1.00
7	10	14	140	31.5	15,810	100	11,582	73.26	216	1.36
8	8	31	310	81.6	15,865	100	10,655	67.16	441	2.78
9	8	[b] 27	529	135	15,688	100	9,206	58.69	861	5.49
10	12	5	50	12.3	15,838	100	11,940	75.39	112	.71
11	0	35	350	114	15,743	100	11,177	70.99	603	3.83
12	0	22	220	63.2	15,915	100	11,186	70.29	431	2.71
13	0	23	230	55	15,680	100	10,539	67.21	361	2.30
14	0	37.5	375	185	15,865	100	9,766	61.56	683	4.32

Test No.	Heat balance.[a]									
	Loss due to moisture—				Heat lost in dry flue gases (4).		Loss due to incomplete combustion of carbon in CO (5).		Loss in escaping hydrocarbons, radiation, and unaccounted for (6).	
	In fuel (2).		Of hydrogen (3).							
	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.
1	78	79	80	81	82	83	84	85	86	87
1	53.1	0.34	539	3.43	2,302	14.65	....	....	21	0.14
2	64.8	.41	542.7	3.45	2,451	15.60	173.6	1.10	170	1.08
3	71.7	.45	529.9	3.36	2,603	16.50	79	.50	741	4.69
4	55.5	.35	525	3.32	2,158	13.64	186	1.18	335.5	2.12
5	50	.32	542	3.42	2.307	14.56	107	.69	908	5.74
6	63	.39	530	3.31	2,384	14.91	176	1.17	914	5.72
7	73	.46	573	3.63	2,795	17 68	189	.88	432	2.73
8	71	.45	591	3.73	2,951	18.61	113	.78	1.043	6.56
9	111	.71	588	3.75	3,340	21.28	117	.74	1,465	9.34
10	34	.21	506	3.19	2,089	13.18	162	1.02	995	6.28
11	49	.31	574	3.65	3,058	19.43	20	.13	262	1.66
12	33	.21	577	3.62	2,894	18.18	227	1.43	567	3.56
13	96	.61	553	3.53	2,821	17.99	38	.24	1,272	8.12
14	78	.50	758	4.75	4,214	26.56	163	1.03	203	1.28

[a] Heat-balance items (designated by numbers in parentheses under this heading) are explained in Bulletin U. S. Geological Survey No. 325, p. 153.
[b] Sparks collected for two hours only.

CONCLUSIONS.

At low rates of working, run-of-mine coal gives a higher equivalent evaporation than briquets; at medium rates there is little difference; at high rates briquets do considerably better.

So far as blackness of smoke is concerned there seems to be little advantage in briquets over run-of-mine coal. However, the loss in sparks is less, and especially with the larger size of briquets.

It is a great deal easier to raise and keep up steam with briquets than with run-of-mine coal. Higher rates of combustion are feasible, and consequently higher power, which is of especially great advantage on long grades.

STEAMING TESTS MADE WITH LIGNITE AT THE RECLAMATION SERVICE PLANT AT WILLISTON, N. DAK.

In the fall of 1908 the steam-engineering section was called upon to make a series of tests of North Dakota lignite at the Reclamation Service plant at Williston, N. Dak. The primary object of these tests was to determine whether the North Dakota lignite is a fuel suitable for steaming purposes. The lignite as it is mined contains on the average about 40 per cent of moisture and about 7 per cent of ash; its heating value is about 7,500 B. t. u.

The tests were made on a Stirling water-tube boiler of 250 boiler horsepower capacity, equipped with a special semigas-producer furnace. In this furnace the fuel was gasified on the grate, the gases passed over the bridge wall into the combustion space, preheated air was added to them through the opening in the bridge wall, and the combustion was completed in the space beyond the bridge wall. The setting is shown in part in figure 79.

There were made in all 15 tests with rates of combustion varying from 19 to 29 pounds of dry coal per square foot of grate area per hour.

A complete description of the tests and the results are given in Bureau of Mines Bulletin 2. The following table presents the principal items of the results:

TABLE 19.—*Principal results of tests made with North Dakota lignite.*

Test No.	Horsepower developed.	Equivalent evaporation from and at 212° F. per pound of coal (pounds).		Efficiency of—	
		As fired.	Dry.	Boiler, figured from analysis of coal and ash (per cent).	Boiler and grate (per cent).
1	202.6	3.50			
2	238.7	3.69	6.33	61.35	60.39
3	275.2	3.43	6.01	58.99	57.47
4	184.7	3.36	6.02	61.23	57.70
5	215.8	3.79	6.28	59.38	58.33
6	243.4	3.30	5.65	56.05	54.42
7	224.8	3.63	6.27	61.46	60.94
8	256.1	3.16	5.62	55.56	53.65
9	220.7	3.46	6.23	60.17	59.04
10	208.7	3.77	6.70	64.24	63.30
11	281.9	3.48	6.10	62.52	59.21
12	283.3	3.58	6.22	59.10	58.86
13	238.0	3.67	6.31	60.47	59.52
14	240.0	3.77	6.54	61.33	61.14
15	229.3	3.03	5.28	51.24	49.64
15A	258.2	3.34	5.83	56.66	54.81

Although the evaporation per pound of coal as fired is low, the over-all efficiency and the capacity of the boiler were as good as are obtained in the average steam plant with a good grade of eastern steam coals. This fact goes to show that the North Dakota lignite is a good fuel for making steam.

PRINCIPLES INVOLVED IN THE COMBUSTION OF COAL IN BOILER FURNACES.

The combustion of coal in a boiler furnace is a chemical process in which the oxygen reacts with the carbon and its various combinations with hydrogen. This reaction being a process between gaseous oxygen on one side and gaseous, liquid, and solid combustibles on the other is very complicated.

The word "liquid" as used in this discussion denotes all types of combustibles between the gaseous and the solid form; that is, such substances as in a strict physical sense are neither gaseous nor solid. For example, if some coal tar in its viscous semi-liquid condition is poured on a hot coal fire, a dense brown smoke will be formed. One knows that this visible smoke is not a gas, because gases are not visible; it is also hard for one to believe that all this smoke consists of tiny angular pieces of solid carbon. At least part of this smoke is composed of minute globules of tar which have been boiled off, somewhat like the visible "steam" issuing from boiling water. For lack of a better expression one can say that the combustible in the globules is in liquid form.

It has been already stated in the section on the composition of gases leaving the fuel bed, that when, in the case of hand firing, a fresh charge of bituminous coal is spread over the hot coke on the grate the coal is heated rapidly and a considerable part of it is distilled off shortly after the coal reaches the fuel bed. This combustible that is distilled off is mostly in gaseous form, and such forms as are in this discussion called "liquids." There is also a small proportion of tiny pieces of solid carbon in the form of lampblack, and even small pieces of coal carried along with the current of the gases.

The combustible left on the grate is fixed carbon in the solid form; it stays on the grate until completely burned or changed into gas. There is sufficient evidence (see p. 280) that in the two or three inches of fuel bed next to the grate or the layer of ash the carbon burns to CO_2, which is decomposed into CO as it passes through the upper layers of the hot coal. The two reactions which take place are represented by the equations:

$$C+O_2=CO_2$$
$$CO_2+C=2CO$$

The temperature of the fuel bed is usually so high that even with a fire that is considered light only a small percentage of CO_2 leaves

the fuel bed; most of it is decomposed and rises into the space as CO. It is therefore important that additional air be supplied over the fire in order that this combustible gas may be burned.

The rate of formation of CO_2 in the lower layer of the fuel bed, and to a large extent the rate of its decomposition in the upper layers, seems to vary directly with the velocity of the air passing through the hot fuel. The higher the blast of air passing through the bed of burning carbon the faster the latter burns. Undoubtedly the scrubbing action of the blast of air removes from the surfaces of the solid carbon the film of the products of combustion and facilitates the access of free oxygen to the surfaces. With the high temperatures at which fuel beds are maintained rapid combustion or gasification of fixed carbon can be obtained without any difficulty if a stream of air is passed through the beds.

The combustible gases which leave the fuel bed during and after the distillation period are free hydrogen (H_2), carbon monoxide, and several of the lighter hydrocarbons. The "liquids" are the heavy hydrocarbons and carbon-hydrogen compounds of the benzene series, which, although surrounded by gases at a high furnace temperature, may exist as minute tar globules. This gaseous and "liquid" combustible must be burned in the combustion space, and the completeness of the process depends on the length of time it stays within the combustion space and on the temperature at which the latter is maintained. All the forms of combustible driven off from the fuel bed are mixed more or less perfectly with the air added through the firing doors or other openings provided for this purpose.

The velocity of chemical reaction (combination) between the combustible gas and the free oxygen (or the rapidity with which the combustible gas burns) depends upon the concentration of the two gases; that is, the rapidity of combustion will be the product of the amount of free oxygen times some power of the amount of combustible gas present in a unit volume. This is the law of mass action, explained at the end of this discussion. The combination of simple gases, such as hydrogen and carbon monoxide, consists of a single reaction, whereas the combustion of the unsaturated hydrocarbons, as ethylene and acetylene, may be a series of two or three, or even more, reactions, the first reactions of each series partly burning the gases and partly reducing them to simpler combustible, either gaseous or solid. Ordinarily, if the mixture is good, these reactions or the burning of the gaseous combustible are nearly complete in possibly a fraction of a second.

The tar vapors, however, being partly in "liquid" form, require, even in the case of a uniform mixture with oxygen, a much longer time for their complete combustion, because oxygen can act only on the surface of each minute globule. As each globule burns, an

insulating film of the products of combustion is formed around it, preventing contact with more oxygen. The globules are carried in the current of gas, and since both have very nearly the same velocity, there is little or no friction between the gas stream and the globules. The chief way in which the insulating film around each globule can be dispersed and more oxygen brought into contact with the surface of the globule is by natural diffusion between the gas comprising the film and the free oxygen outside the film. This process of natural diffusion is rather slow, and as each globule contains many times more combustible matter than a like volume of gas, the process of oxidation of the globules of tar may extend over a considerable length of time, during which they may be carried out of the furnace and cooled below their ignition temperature. Such unoxidized tar globules appear at the top of the stack as a dark smoke and probably form the greater part of the loss in incomplete combustion.

These tar globules are similar in character to tobacco smoke, which is not a product of combustion, but a product of decomposition; it is not a slightly colored gas, but a large number of small tobacco-oil globules held in suspension by the current of gas. Every smoker knows that if he passes the smoke from his cigar through a clean white linen cloth, the visible smoke, which consists of the tobacco-oil globules, will condense and leave a light-brown oil spot on the linen, having a strong characteristic smell. The tarry globules escaping from a coal fire, if collected and condensed in some such way, generally appear as a thick, black, pasty liquid having the strong coal-tar odor, that we are accustomed to smell around a certain class of gas producers or around gas works. Tar vapors from a wood fire differ in odor from those coming from a coal fire. In fact, every fuel gives off tar vapors with odors peculiar to that fuel and somewhat different from those of any other.

In the case of a boiler furnace, any attempt to determine the tar loss by volumetric chemical analysis of the fuel gases must necessarily fail because these tars have comparatively little volume; furthermore they generally condense in the gas-sampling apparatus.

The slow combustion of the tar globules can be made faster by increasing the rate of diffusion of the film of products of combustion enveloping the globules. This can be done by creating a relative velocity between the gas stream and the globules; that is, by making one move faster than the other or by changing slightly the direction of the main stream of gas. The resulting friction facilitates diffusion by a process of scrubbing, which removes from the globules the insulating film of products of combustion. Insertion of brick piers in the path of the gases or changing the cross section of the gas passages so that the gases have to contract and expand induces such relative velocity.

That some such film as is herein described does prevent the free oxygen from coming into contact with the surface of the globules seems to appear from the fact that gas samples taken with water-jacketed samplers from a stream of gas apparently rich in the tar vapors show usually several per cent of free oxygen.

As the tar vapors are perhaps a whole series of very complex hydrocarbons, their complete oxidation undoubtedly consists of several simultaneous or consecutive reactions more or less dependent on each other. This is probably another cause of their slow combustion.

What has been said about the slow combustion of the tars is perhaps in a large measure true of the small particles of solid combustible held in suspension by the gases.

In the preceding discussion of the combustion of the various forms of combustible in a boiler furnace it has been shown that the gaseous combustible is easy to burn because it burns quickly, and that the fixed carbon is easy to burn or gasify because it stays on the grate until completely burned or gasified; also that the tar vapors, the lampblack, and the tiny pieces of coal held in suspension by the gases are difficult to burn because they burn slowly, and usually can not be kept within the furnace long enough to be completely burned. The proper way to burn coal would be to treat it in such a way as to distill as volatile matter only light, easily burning gases, and leave all the rest of the combustible on the grate and burn or gasify that while it stays there. Laboratory experiments [a] show that the amount and quality of the combustible driven off the coal by heating depend largely on the rate of heating; that is, when the rate of heating is slow, the total combustible matter driven off as volatile is small in quantity and gaseous in composition, while if the rate of heating the coal is very rapid the total volatile matter driven off is not only high in quantity but contains much tar vapor. It seems as though the hydrogen of the coal must be distilled off before burning, and that when the coal is heated slowly the hydrogen on distillation takes only a small amount of carbon with it, leaving most of the latter on the grate as fixed carbon. If, however, the coal is heated very rapidly, the hydrogen comes off with a large amount of carbon and escapes as volatile matter, leaving a smaller quantity of the carbon on the grate in a fixed form. These facts bring one to the realization that there is no definite line between fixed carbon and volatile matter. One knows, for instance, that coal tars which escape from a gas producer entirely as volatile matter show 40 to 50 per cent of fixed carbon when subjected to proximate analysis. Similarly, if the tars from a boiler furnace, particularly from a hand-fired one, were caught and analyzed by the proximate method, they would

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[a] See Bulletin 1, Bureau of Mines.

likely show a considerable percentage of fixed carbon. This fixed carbon of the tar should have been left on the grate and not carried away by the process of distillation.

According to the above reasoning, firing coal by hand is not the right way to burn it, because the pieces of coal fall on a very hot fuel bed and are heated in two or three minutes through a range of temperature of about 2,400° F. This is a very high rate of heating, and much of the carbon that with a slow heating would be left on the grate as fixed carbon, is driven away in combination with hydrogen in the form of heavy tar vapors. These tar vapors generally do not stay long enough in the furnace to burn completely and hence leave the stack as smoke.

Most mechanical stokers are designed so that the coal is fed into the furnace gradually, and therefore the rate of heating is slow. The result is that a comparatively small amount of combustible is driven off as volatile matter, and that which is driven off consists chiefly of easily burning gases. Most of the carbon is left on the grate in the fixed form, where it is either burned or gasified; very small amounts of tarry vapors are distilled, whence the success of most mechanical stokers in burning smoky fuel. As an example, on a well-operated chain grate stoker, it takes perhaps 15 to 20 minutes to heat the coal through the same temperature range of 2,400° F., whereas this heating extends over only two or three minutes in a hand-fired furnace. In general the success of these mechanical stokers lies not in the fact that they consume smoke but in that they burn coal without producing smoke at all.

The tar vapors and other heavy carbon-hydrogen compounds, which are the products of distillation of coal under certain treatment, burn slowly, and in order to burn them completely they must be kept a comparatively long time within the furnace. To fulfill this condition the furnace must be provided with a large combustion space. Such furnaces, however, are objectionable for obvious reasons. The remedy probably is to avoid the formation of these slow-burning volatile compounds by using the principle of slow heating.

Although the space necessary for complete combustion may be considerably reduced by the slow and gradual heating of the coal, nevertheless, some space must always be provided for the burning of the gases which rise from the fuel bed even though the tar vapors be absent. If all other conditions are kept constant the volume of gases leaving the fuel bed varies directly as the rate of combustion or the rate of gasification. Therefore to obtain the same completeness of combustion the space in the furnace should be in proportion to the rate of combustion, or, more correctly, the combustion space should be proportional to the volume of the gas leaving the fuel bed. It is not always practical to carry out this relation. There are cases in

which the space available for the entire steam-generating apparatus is too small compared with the steaming capacity of the apparatus. In such cases the combustion space of the furnace is often reduced to a mere fraction of the required volume needed for a practically complete combustion. Under such conditions not only do the tar vapors but also a considerable amount of the easily burnable gases leave the furnace unconsumed.

To show how small the combustion space is in some boiler furnaces Table 20 is presented. In the table is given, for three furnaces, the usual relation of combustion space to grate area, the rate of combustion, and the average time each cubic foot of gas is allowed to stay in the furnace.

TABLE 20.—*Usual relation of combustion space to grate area, the rate of combustion, and the average time each cubic foot of gas stays in the furnace.*

Type of furnace.	Grate area (square feet).	Combustion space (cubic feet).		Ratio of columns—		Customary rate of combustion (pounds of fuel per square foot of grate area per hour).	Gases generated per second (cubic feet).[a]	Time each cubic foot of gas stays in furnace (seconds).
		Total.	Effective when fuel bed is 1 foot thick.	3 and 2	4 and 2			
1	2	3	4	5	6	7	8	9
Torpedo boat *Biddle*	58.6	136	78	2.34	1.33	40	1,010	0.077
Modern locomotive	30	160	130	5.34	4.33	60	780	.17
Stationary boiler, Heine, 200 horsepower	35	250	215	7.14	6.14	25	380	.58

[a] Assuming that 20 pounds of gas and water vapor are formed per pound of coal and that the furnace temperature is 2,500° F.

Columns 5 and 6 show that the ratio of combustion space to grate area in the torpedo-boat furnace decreases much more rapidly with the thickness of fire than it does in either of the other two furnaces. A thick fuel bed not only makes the gases richer in combustible but also reduces the space in which this combustible gas is to be burned.

Column 9 gives approximately the average length of time each cubic foot of gaseous mixture is allowed to stay in the combustion space of the furnace. In the case of the torpedo-boat furnace the time is very short; in fact, it is too short for any chemical reaction which is not almost instantaneous like that of an explosion.

The bad conditions of combustion due to small combustion space are usually made worse by inadequate mixing of the gases. It has been shown in the section on the composition of gases at various parts in the furnace that the gas leaving the fuel bed is very rich in combustible and deficient in free oxygen. It is therefore always necessary to add air to the gases rising from the hot fuel. If the air is admitted

through large openings, like the firing doors, it may pass through the furnace as one solid stream alongside of another large stream of combustible gas, without materially improving the completeness of combustion. It is obvious that in order to help the combustion, the air must not only be admitted but must be intimately mixed with the combustible gas if the latter is to be completely burned in the short time that it is allowed to stay within the furnace. Thus it can be seen that the mixing of the gases is an important factor affecting completeness of combustion, particularly where the combustion space is small.

LAW OF MASS ACTION APPLIED TO COMBUSTION OF GASES IN THE BOILER FURNACE.

The law of mass action states that the speed of any chemical reaction is proportional to the products of some powers of the weights of the reacting substances present in a unit of volume; that is, if one molecule of substance A reacts with one molecule of substance B, the velocity of the reaction at any time will be directly proportional to the product of the molecules (or the weight expressed in gram-molecules) of each substance present in a unit of volume. Reactions of this kind are said to be of the second order. If one molecule of substance A reacts with two molecules of substance C the velocity of the reaction will be proportional to the number of molecules (or the weight expressed in gram-molecules) of substance A in a unit of volume multiplied by the square of the number of molecules (or the weight expressed in gram-molecules) of substance C. Reactions of this kind are said to be of the third order. It can be said that in any case the speed of the chemical reaction increases when the weight (in gram-molecules) of the reacting substance in a unit of volume increases, although the relation may not be a simple proportion.

The law of mass action is one of the most firmly established and useful of the laws of physical chemistry. Its operation is a matter of daily observation in other fields; for example, the more water one uses the easier it is to dissolve sugar, salt, and other soluble substances. Only recently has the law been mathematically formulated in chemistry. It is often hard to learn what the reactions are and what formula to use; still the path of a great many reactions has been determined by experiments and by finding what formula fitted the observed results.

In the case of combustion of coal the law of mass action manifests itself by the fact that in most furnaces a considerable excess of air is needed above the theoretical requirement to insure practically complete combustion within the furnace. If the air supply is reduced to near the theoretical amount the combustion of the gases is slow and a long time is required to burn them. The time is so long that usually a large percentage of these gases leave the furnace before

they are burned. It can be easily seen that if there are two molecules of carbon monoxide and ten molecules of oxygen in a unit volume, the chances of one molecule of oxygen meeting the two molecules of carbon monoxide are a great deal more than if there were only one or two molecules of oxygen in the same unit of volume. When in the mixture of air and furnace gases some oxygen unites with carbon monoxide, this oxygen is no longer available for oxidation of the remaining combustible; worse yet, the molecules of the products of combustion formed are in the way, so that the remaining molecules of oxygen meet the remaining molecules of combustible gas less frequently. As the combustion proceeds, the masses or molecules of free oxygen and combustible gas become less and less compared with the total mass of gas present and their combination becomes slower until it is nearly zero; whence the name mass action.

The weight or mass of chemical substances when used in connection with the mass-action law is always measured in gram-molecular units. Elementary chemistry states that carbon monoxide and oxygen combine in just one proportion—28 parts by weight of carbon monoxide (its molecular weight) and 16 parts by weight of oxygen (its atomic weight). Inasmuch as free oxygen does not exist in atoms, one molecule of oxygen and two of carbon monoxide should really be considered; the ratio of the weights would then be 56 parts of carbon monoxide to 32 parts of oxygen, which is the same proportion as 28 to 16. For these reasons both combining substances must be considered according to the number of gram molecules present; that is, the number of grams of each gas present divided by its respective molecular weight. Luckily this trouble disappears when working with gases analyzed volumetrically, as with an Orsat apparatus, because the volumetric weights of gases are directly proportional to their molecular weights, as all gases at the same temperature and pressure contain the same number of molecules in the same volume. In working with the law of mass action all that is necessary is to substitute the volumetric percentages of O_2, CO, and CH_4 in the equation corresponding to the particular reaction and obtain the relative indication of the rate of combustion, assuming, of course, the same temperature and the same pressure in every case.

Example: An analysis of gas collected with a water-jacketed gas sampler from the rear of the combustion chamber showed the two following results, the combustion chamber temperature in each case being 2,600° F.:

(1) $O_2 = 4$ per cent; $CO = 0.5$ per cent.
(2) $O_2 = 7$ per cent; $CO = 0.4$ per cent.

The remainder of the sample consisted of nitrogen, water vapor, carbon dioxide and other gases. What is the relative velocity of

combustion of CO in each of the two cases? The formula of the reaction is $2CO + O_2 \rightleftarrows 2CO_2$.[a]

At a temperature of 2,600° F. the dissociation of CO_2 is only about 0.01 per cent. Therefore, one may say with close accuracy that the reaction at this temperature is not reversible but proceeds to a finish. It can be written:

$$2CO + O_2 = 2CO.$$

If the rate of combustion of CO in the gas is given by the equation

$$\frac{d(CO)}{dt} = \text{A constant} \times (CO)^2\ (O_2),$$

the relative rates of combustion in the two cases are:

$$(1)\ 4 \times 0.5^2 = 1;\quad (2)\ 7 \times 0.4^2 = 1.12.$$

Thus the net velocity of combustion in the second case is greater on account of more oxygen, although there is a less percentage of carbon monoxide.

Another example: Assume that the gas mixture over the front part of the bridge wall and in the rear of the combustion chamber contains the following percentages of CO and O_2, what are the relative rates of combustion of CO at each place?

The gas over the front part of bridge wall contains 10 per cent of CO and 9 per cent of O_2.

The gas at the rear of the combustion chamber contains 0.6 per cent of CO and 4.5 per cent of O_2.

The rate of combustion of CO over the bridge wall is

$$9 \times 10^2 = 900$$

when the rate of combustion of CO in the rear of the combustion chamber is

$$4.5 \times 0.6^2 = 1.62.$$

The preceding figures show that the rate of the combustion of CO is over 500 times as fast over the bridge wall as it is in the rear of the combustion chamber.

It must be constantly borne in mind that calculations of velocity of reactions based on the laws of mass action are liable to be seriously in error owing to disturbing side reactions; but probably less is to be feared here with simple gases at high temperatures than with more complex substances at ordinary temperatures. At any rate, these laws of mass action are a valuable guide in such problems, and if the facts do not fit proved formulas well, too little theory has been applied, and some refining corollaries must be added.

The question may arise: How are we to treat cases in which more than one combustible is present? Simply by adding the two effects together, as when we say that the pressure of a mixture of gases on

[a] The sign $\rightleftarrows$ indicates that a chemical combination and a decomposition are going on side by side. The composition of the mixture changes according to the relative rapidity of combination or dissociation.

the walls of a containing vessel is the sum of the pressures of the constituent gases; the two reactions go on independently side by side. Care must be taken not to add these velocity products without having first multiplied each by its proper reduction factor, which, for most substances, is at present imperfectly known for high temperatures. For the present, therefore, it is not feasible to get an expression for the comparative total velocities of combustion of all constituents taken together at several points along the flame.

Thus far the law of mass action as applied to the combustion of gases has been considered. The law is also a valuable guide in the study of the combustion of the fixed carbon on the grate, which is a chemical reaction between a solid and a gas. In this case the mass of the solid carbon is almost infinite compared with that of the gaseous oxygen so that the velocity of the reaction depends only on the mass of the oxygen coming in contact with a unit surface of the hot pieces of coke. The faster the oxygen is supplied to the surface of the carbon the higher the velocity of the reaction. This principle is utilized in a blacksmith forge and in all blast furnaces. The oxygen of the air is blown in at high velocities and the gaseous products of combustion are quickly removed and free oxygen brought in contact with the surface of the hot solid carbon. The high velocity of the air simply keeps the mass of free oxygen against the surfaces of the carbon at high pressure.

If the same method of supplying oxygen could be applied to the combustion of the tar globules they would be much less troublesome. However, they are so small that they quickly adopt the motion of the surrounding gas and consequently there is little or no relative velocity between the two, to scrub off the layer of the products of combustion and increase the mass of the free oxygen acting against the surfaces of the globules. The removal of the products of combustion and the supplying of free oxygen must be largely accomplished by natural diffusion, which is a slow process. This is the reason that the process of combustion of the tar globules is slow.

In the commercial combustion of fuels, where the speed of burning coal is important for obtaining high capacity, the operator must determine whether he will be most benefited by high temperatures or by a close approach to complete combustion. If he must put the heat into material at high temperature, as in melting pig iron or fusing cement, he must cut down the air supply even at the cost of a large fall in completeness of combustion due to decreased oxygen mass action, so as to have the temperature of the gases as high as possible above that of the material to be worked. If the temperature of his material is low, as is the water in a boiler, it does not make much difference within reasonable limits how much air he uses so far as heat absorption is concerned; larger proportions of air mean

larger oxygen mass action and more complete combustion. Of course this increased air supply can be easily carried to extremes and large heat losses in the stack may result. As a general rule the air supply per pound of fuel must be decreased at a sacrifice of completeness of combustion, when the temperature of the material into which heat is to be put is high.

PRINCIPLES INVOLVED IN HEAT TRANSMISSION IN STEAM BOILERS.

The heat evolved by the combustion of fuel in the furnace is contained partly in the residue on the grate, but mostly in the gaseous products of combustion. From these substances the heat is transmitted first to the heating plates of the boiler and then through them to the water on the inside of the boiler. The path of heat travel consists of three distinct parts, as follows:

(1) From the hot gas or the hot fuel on the grate to the dry surface of the heating plate. This is the most important part of the path, because it is the slowest and the most tortuous part for the heat to pass over; this part, however, seldom receives due consideration in the design of the boiler or any apparatus involving the problem of heat transmission in general.

(2) From the dry surface to the wet surface of the plate; this is the only part that is usually considered.

(3) From the wet surface of the boiler plate into the body of the boiler water; this is perhaps the easiest part of the path.

In passing over these three parts of the path the heat travels in three ways: In the first part of its path it passes from the hot fuel bed, hot flames, or from any incandescent substances in the furnace to the dry surface by radiation. From the hot gases the heat passes to the dry surface by convection; that is, the motion of the particles of gases brings them in actual contact with the dry surface and they impart their heat to it. As a very large percentage of the heat evolved in the furnace is contained in the gases this last mode of heat travel is the most important one in the problem of steam generation. The heat, then, reaches the dry surface of the heating plate by radiation and convection. Between the dry and the wet surface the heat travels through the plate by conduction; this mode of heat propagation is well understood and its principles are frequently used in working out thermal problems. From the wet surface of the plate the heat passes into the water by convection; that is, the particles of water come in contact with the wet surface and after absorbing some heat are changed partly, or wholly, into steam and are pushed away by other particles of water which have capacity to absorb heat. This exchange of heat-containing water particles for particles which have capacity for absorbing heat is identical to circulation of water and is

the result of the difference between the density of the particles of water and that of steam.

Figure 85 shows diagrammatically the three parts of the path of heat travel from the hot gasses and the hot fuel through the metal of the heating plate to the boiler water. The diagram also shows the ways the heat travels over this path.

The diagram illustrates the heating plate on the gas side covered with a layer of soot and on the water side with a layer of scale. Next to the soot layer and entangled in its recesses is a layer or film of motionless gas. This film of gas under ordinary conditions adheres so tightly to the soot or metal, that it may be considered a part of the solid plate. It is therefore reasonable to assume that the dry surface of the plate is a thin region of gas near to, or at, the outside surface of the soot coating where the heat ceases to travel by convection and starts to travel by conduction. The wet surface of the heating plate is located in a similar film of water and steam adhering on the inside of the boiler to the layer of scale. It can be defined as the thin region of steam and water near, or at, the surface of the layer of scale where the heat ceases to travel by conduction and starts traveling by convection.

FIGURE 85.—Diagram showing methods by which heat enters, travels through, and leaves a boiler plate.

It may be well to explain, briefly, the three ways by which heat travels.

Conduction of heat is the process by which heat flows from a hotter body to a colder one, when the two are directly in contact, or from one part of a body to a colder part of the same body. Conduction of heat implies no visible or mechanical motion of bodies or parts of the same body, but implies a direct contact. In the case of a boiler the heat passes by conduction from the particles of hot gas which come into contact with the soot coating, into the latter, and then through the metal and scale into the particles of water next to the scale.

Radiation is a process by which heat passes through space from one body to another without any material agency; that is, the two bodies do not come into contact directly or by means of a third body or bodies. In the case of a boiler furnace and a boiler plate, heat flows by radiation from the hot fuel bed and flames through the space filled with gases directly into the boiler plate without heating the

gases appreciably. The amount of heat transmitted by radiation would not be lessened if the gases did not fill the space; in fact it would be slightly greater if there were a vacuum between the fuel bed and the plate.

Convection of heat from one place to another always implies the motion of a fluid receiving or giving up the heat. Thus, in the case of hot gases and the boiler plate, heat is imparted to the plate by small particles of gas moving from the body of the gas toward the plate and imparting their heat to the latter when in contact with it. In other words, convection is the process of continuous interchange of the cooled particles of gas next to the surface and those farther away within the body of the gas. It is evident that the amount of heat imparted to a unit of dry surface of the plate depends on the rate of exchange of the particles of gas.

Each of the three modes of heat propagation is governed by a distinct law which is different from those governing the other two modes. These laws as applied to the steam-boiler problem are briefly stated in the following paragraphs. An example of the application of the law follows each statement.

CONDUCTION.

The quantity of heat which can be transmitted through a unit area of heating plate in a unit of time depends on the difference of temperature between the dry and the wet surfaces of the plate, the conductivity of the substances on or in the plate, and the distance between the two surfaces. This law can be expressed by the following simple formula:

$$H = \frac{C}{d}(t_1 - t), \tag{1}$$

in which

H = the quantity of heat transmitted per unit of area of heating plate,

C = the average conductivity of the substances between the dry and the wet surface,

d = the distance between the two surfaces,

t_1 = the temperature of the dry surface, and

t = the temperature of the wet surface.

This law governing the rate of heat transmission by conduction is the same as Ohm's law, much used in electrical conduction problems.

It is evident that with any physical condition of the plate and the surfaces, the rate of heat transmission depends entirely on the excess of the temperature of the dry surface over that of the wet surface. For example, if it is required to transmit twice the quantity of heat in the same length of time, the difference between the temperatures of the two surfaces must be doubled. Since the temperature of the wet surface is nearly the same as that of the steam in the boiler and,

therefore, can not be lowered, the temperature of the dry surface must be raised. As it is this dry surface of the heating plate which cools the furnace gases, the rise of its temperature results in a rise of the temperature of the escaping gases. Thus we see that, with the same conditions of the heating plate and the same initial temperature of the furnace gases, the temperature of the escaping gases will rise somewhat with increasing capacity. This law can be illustrated by the following specific example:

At normal capacity 1 square foot of heating plate of a boiler transmits on the average

$$3.5 \times 965 = 3{,}378 \text{ B. t. u. per hour, or}$$

$$\frac{3{,}378}{60 \times 60} = 0.948 \text{ B. t. u. per second} = H \text{ in equation (1).}$$

In the Smithsonian Physical Tables the heat conductivity of iron at 400° F. is given as about 0.0005. This means that if the two surfaces of an iron plate 1 inch thick are kept at a temperature difference of 1° F., every square inch of the plate transmits 0.0005 B. t. u. per second; or every square foot transmits $0.0005 \times 144 = 0.072$ B. t. u. per second. This value is C in equation (1).

Now the walls of a tube in a water-tube boiler are about 0.1 inch thick. This value is d in equation (1). We have, then, all the values excepting the temperature difference $(t_1 - t)$ which we can easily compute by substituting the previously obtained values in equation (1).

$$.948 = \frac{0.072}{0.1}(t_1 - t).$$

Therefore $$(t_1 - t) = \frac{0.0948}{0.072} = 1.32° \text{ F.}$$

This is a surprisingly small temperature drop. Even if the resistance of the heating plate to the passage of heat was increased 10 times by the presence of the soot and scale in a normally clean boiler tube, the temperature drop between the two surfaces of the plate would be only 13° F. It is certain that with a normal rate of working the temperature of the wet surface of the plate is not very much higher than the temperature of the steam in the boiler, probably less than 15° F. If that is the case the temperature drop from the dry surface to the boiler water is only about 25 or 30° F. at the normal rate of working. For 10 times the normal rate of working this temperature drop would be 250 or 300° F., which is only a small fraction of the total temperature difference between the furnace gases and the boiler water.

The previous calculation, although only approximate, indicates that the heat passes rather easily from the dry surface through the

heating plate into the boiler water, but that the process of heat impartation by the furnace gases to the dry surface is slow and is that part of the path of the heat travel which is responsible for the present low rate of working steam boilers.

Figure 86 shows the approximate temperature drop from the gases to the boiler water when the boiler works at 10 times the normal rate of working. The figure is based on the calculations made in the preceding discussion. It is apparent from the figure that the problem of working a steam boiler at high capacity is not so much a question of how much heat the heating plates of a boiler will transmit, as of how much heat can be imparted to the dry surface of the heating plates. It is that part of the heat path from the hot gases to the dry surface of the heating plate which should receive a thorough consideration when designing a boiler for high rates of working.

FIGURE 86.—Diagram showing the approximate difference between the temperature of the hot gases and the temperature of the boiler water when working a boiler at 10 times its normal rating.

RADIATION.

In the ordinary water-tube boiler the quantity of heat imparted to the dry surface of the heating plate by radiation is small. In the internally fired types, however, the heat thus received may amount to a considerable percentage of the total heat absorbed by the boiler.

The quantity of heat which a heating plate exposed to radiation receives is approximately proportional to the difference between the fourth powers of the absolute temperatures of the hot parts of the furnace and the sooted surface of the boiler plate. This law of radiation is known as the Stefan and Boltzmann law.[a]

About 30 years ago Stefan deduced this law from experimental results, and some years later Boltzmann demonstrated mathematically that, from the principles of thermo-dynamics, the fourth-power law should hold exactly for an ideal black body. Inasmuch as the sooted surface behaves nearly like a black body (within 3 or 4 per cent), the fourth-power law can be used without any serious error in

[a] For detailed discussion of this law see Bulletin 2, article on Optical Pyrometry, Bureau of Standards, Washington, D. C.

all radiation problems in connection with the steam boiler. The radiation law is expressed by the following equation:

$$H = C\ (T_1^4 - T_2^4), \tag{2}$$

in which

H = the net heat exchanged between the hot and cold surface per unit of hot surface per unit of time,

T_1 = the absolute temperature of the hot surface,

T_2 = the absolute temperature of the cold surface which surrounds the hot surface, and

C = a constant depending on the unit of area and time, on the unit in which the heat is measured, and on the scale in which the temperature is expressed.

When H is expressed in B. t. u. per square foot of hot surface per minute and T_1 and T_2 are expressed in degrees Fahrenheit, then

$$C = 2.66 \times 10^{-11} = \frac{2.66}{100{,}000{,}000{,}000}$$

This constant is good only when the hot surface is completely surrounded by the cold surface or when the conditions are such that the hot surface may not "see" anything else but the cold surface. The radiation from the hot fuel bed to the surrounding sheets of the fire box of a locomotive boiler approaches this ideal condition very closely. It should be stated in this connection that when the temperatures remain constant the amount of heat received by the boiler by radiation depends on the extent or area of the fuel bed and not on the area of the boiler's heating surface exposed.[a]

Figure 86 is a graphical representation of equation (2). Each of the three curves has been platted for one value of T_2, as indicated in the figure. In computing the values from which the curves were platted, C in equation (2) was taken to equal $\frac{2.66}{100{,}000{,}000{,}000}$. The abscissas of the figure are the temperatures of the hot surface, and the ordinates give the quantity of heat in B. t. u. per minute radiated by every square foot of the hot surface to a surrounding cold surface at the temperatures given by the three curves.

To show the significance of the radiation let us use figure 87 in working out a specific problem.

Assume that a given locomotive boiler has a grate area of 40 square feet and the temperature of the fuel bed is 2,460° F., absolute, or 2,000° F. on the ordinary scale. Assume, further, that the steam pressure and the condition of the heating plate are such that the dry surface is at 1,000° F., absolute, or 540° F. on the ordinary scale. What is the rate of heat transmission by radiation from 1 square foot of the

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[a] For more complete discussion of the radiation law as applied to steam boilers see chapter on radiation in Bureau of Mines Bulletin No. 18, entitled "Heat Transmission into Steam Boilers."

hot fuel bed? The answer to this problem can be obtained from the figure in the following way: Follow the vertical line of 2,460° F. absolute, the temperature of the hot surface, which in this case is the fuel bed, to the intersection point with the curve of constant temperature of the sooted surface of 1,000° F. absolute. From this intersection follow a horizontal line to the scale at the left, which gives the heat radiation per minute for each square foot of the fuel bed as 960 B. t. u. Now, if one wishes to know how many boiler horsepower this radiation represents he can obtain it from the following equation:

$$\text{B. HP.} = \frac{960 \times 60 \times 40}{965 \times 34.5} = 69.2.$$

Usually the temperature of the fuel bed is considerably above 2,000° F.; perhaps 2,400° F. is nearer to the average fuel-bed temperature. This value for T_1 gives the radiation of each square foot of fuel bed per minute as about 1,800 B. t. u., or nearly twice as much as when the fuel-bed temperature is 2,000° F. It is apparent from the shape of the curves that at high temperatures a small rise in the fuel-bed temperature greatly increases the quantity of heat radiated by the bed.

The curves also show that when the temperatures of both of the surfaces increase the heat radiated from the hot surface to the cold one increases, even though the difference between the two temperatures remains constant. Thus when the temperature of the cold surface is 1,000° F., absolute, and that of the hot surface 1,400° F., absolute, the heat exchanged between them is about 73 B. t. u. per minute per square foot of hot surface totally surrounded by the cold surface. When the temperature of the cold surface is 1,500° F. and that of the hot one is 1,900° F., the heat radiated to the colder surface is about 215 B. t. u., or about three times as much as in the first case, although the difference between the temperatures of the two surfaces is the same in both cases.

B.T.U. RADIATED PER MINUTE PER SQUARE FOOT OF HOT SURFACE COMPLETELY SURROUNDED BY COLD SURFACE.

TEMPERATURE OF HOT SURFACE, °F, ABSOLUTE.

FIGURE 57.—Curves showing the quantity of heat transmitted by radiation from a hot surface to a cold surface that completely surrounds it.

This is an important feature in connection with the rate of heat radiation and should never be lost sight of when insulating heat at high temperatures. In this respect the rate of heat radiation is unlike the rate of heat conduction; the heat conducted from one part of a body to another part is the same so long as the difference of temperatures is constant, no matter what the temperatures are. One may draw this general rule for insulating heat: When a body is at low temperature, as in the case of a refrigerator, the heat of the outside atmosphere is kept out of the refrigerator by avoiding conduction of heat; this can be done by putting air spaces in the walls of the refrigerator. In thermos bottles this principle is carried still further and a vacuum space is used instead. In these cases the temperatures are low and the heat radiated across is an insignificant quantity.

When the heat is at high temperature, as in the case of a furnace, the dissipation of the heat from the furnace through the walls can be reduced by avoiding radiation; this can be done by building solid walls of nonconducting materials.

The temperature effect on the rate of heat radiation is recognized by the makers of thermos bottles, who advertise that cold liquids can be kept cold 72 hours, while hot liquids can be kept hot only 24 hours.

When considering the rate of heat radiation in connection with the furnace and boiler, in which case rapid transmission of heat is desirable, high temperatures of fuel beds are advantageous, as they greatly increase the capacity of the boiler.

CONVECTION.

In modern water-tube boilers by far the greater percentage of the total heat absorbed by the boiler is imparted to its heating surfaces by convection. Furthermore, the gases, as they pass along the heating surfaces, are cooled by convection, and therefore the extent of the reduction of temperature of the gases before they finally leave the boiler is dependent solely on the activity of convection. It has already been shown in the paragraphs on the conduction of heat that in the problem of working steam boilers at higher rates it is not a question of how much heat can be transmitted through the heating plate, but a question of how much heat can be imparted to its dry surface. All these facts make it imperative that in designing steam boilers particular consideration should be given to details that may improve the rate of heat impartation by convection. Therefore the study of the factors governing the rate of heat travel by convection is perhaps the most important part in the general problem of heat tranmission in steam boilers.

Perhaps Prof. Osborn Reynolds was the first to publish the results of a study of the law governing the rate of heat tranmission by con-

vection. His results were presented as a paper before the Literary and Philosophical Society of Manchester, England, in 1874. This paper was entirely overlooked by engineers and almost forgotten until, a few years ago, Prof. John Perry accidentally came across it and realized its great value. Perry added to the practical importance of the principles evolved in Reynolds's paper. Perry's work on this subject is published as a part of his book entitled "Steam Engines, and Gas and Oil Engines."

The principle that is brought out in Reynolds's paper and is the foundation of the law governing the rate of heat transmission by convection may be stated, when applied to steam boilers, as follows:

The quantity of heat brought by the gases to the heating plates of a boiler, apart from the effect of radiation, is proportional to the rate at which particles or molecules pass backward and forward from the dry surface to any given depth within the stream of gas.

The rate of motion of the particles of gases to and from the dry surface of the plate depends on two things:

(*a*) The natural internal diffusion of the gas when at rest.

(*b*) The eddies caused by visible motion, which mixes the fluid and continually brings fresh particles of the gas into contact with the dry surface.

In his paper Reynolds expressed this law of heat transmission by convection by the equation:

$$H = A\ (T-t) + C\,qv\ (T-t) \qquad (3)$$

in which

H = the quantity of heat imparted by the gas to a unit surface of the metal,

$(T-t)$ = the temperature difference between the metal surface and the gas,

q = the density of gas,

v = the velocity of gas over the dry surface,

A and C are constants depending on the nature of the gas.

The first term on the right side of the equation expresses the effect of the natural diffusion of the gas. The value of this term depends only on the difference of temperature between the gas and the metal.

The second term expresses the effect of diffusion caused by the motion of the gas. The value of this term depends on the density of the gas, the velocity of the gas, and on the difference of temperature between the gas and the dry surface.

The validity of the first term will be perhaps generally admitted because it contains the temperature factor only. The second term, however, on account of the density and the velocity factor may need some explanation.

It has been stated that the rate of heat impartation by a gas to the dry surface of the heating plate is directly proportional to the

rate at which particles of gas pass to and from the surface. Now, the density of gas is proportional to the number of gas particles or molecules in a unit of volume. When there are more particles of gas in a unit of volume next to the metal surface, proportionately more gas particles or molecules come in contact with a unit of its dry surface. At constant pressure the density of the gas varies inversely as the absolute temperature; therefore as the temperature of the gas rises the gas expands and fewer of its particles or molecules are in action against the dry surface in a unit area. Therefore, there is a partial neutralization of the gain caused by higher temperature difference between the gas and the dry surface.

In considering the velocity factor a mental image should be formed of the appearance of an intensely magnified cross section of the dry surface of the plate. Among the tiny recesses of the layer of soot are entangled particles or molecules of gas held close together in a dense film by the attraction of the solid; farther away from the surface the gas particles are wider apart and are free to move. Now, gas is a very poor conductor of heat, and if its conduction were depended on, the process of transferring heat from the moving gas to the adhering film would be very slow. The only quick way of getting heat into the adhering film is to dislodge the cold particles or molecules from the adhering film of gas next to the soot coating and replace them by hot ones from the moving body of hot gas. This exchange of the cold gas particles by hot ones is effected partly by the natural diffusion of the gas (first term of equation (3)), but mostly by the eddies caused by the motion of the gas over the heating plates. The faster the gas moves the greater is the number of its particles passing each square inch of the dry surface in a unit of time, and consequently the greater is the number of the particles of the moving gas penetrating into the adhering gas film and replacing its cold gas particles. Thus the dislodging effect of these moving gas particles on those of the adhering film is proportional to the velocity of the mass of the gas moving over the heating plate. It is this dislodgment that makes a boiler respond, with reference to the amount of steam made, to any reasonable demands put on it.

The temperature factor $(T-t)$ is perhaps self-evident and needs no further explanation.

Referring to equation (3) one can see that if the velocity of the gas continues to increase the second term on the right side of the equation becomes so large that in comparison with it the first term is very small and may be dropped out of consideration. Thus for high velocities of the gas, equation (3) can be reduced to the following form:

$$H = Cqv\ (T-t). \tag{4}$$

This is the same equation Perry derived mathematically in his book.[a]

The influence of the velocity of gases on the rate of heat absorption may appear at first improbable. However, as high capacities of all types of boilers are obtained simply by burning more coal, which means making more hot gases and passing them over the heating plates at a higher velocity, it must be admitted that such an influence exists. Thus, for example, in locomotive practice the capacity is increased two or three times by doubling or tripling the rate of combustion and thereby doubling or tripling the velocity through the boiler flues. Of course, the rate of heat absorption by the fire box is affected principally by the initial temperature.

Equation (4), although not as accurate as equation (3) is more practical on account of its simplicity. Although there are three factors on the right side of the equation only two of them are independent of each other. These two factors are the velocity and the temperature difference (it has already been stated that the density depends for its value on the absolute temperature of the gases). High temperature differences can be obtained by reducing the air supply. However, as a certain amount of air is necessary for the complete combustion of the fuel, this method of raising the temperature of the products of combustion has its limit which can not be exceeded. Besides, high temperatures decrease the density of the gas, and this fact, as already mentioned, partly neutralizes the gain for higher temperature difference. On the other hand, the velocity factor can be increased almost without limit. This latter is the factor that in the future will be utilized to work steam boilers at high capacities.

EFFECT OF AIR SUPPLY ON THE TEMPERATURE OF THE PRODUCTS OF COMBUSTION AND ON THE RATE OF HEAT ABSORPTION.

Figure 88 shows graphically how the air supply affects the temperature of the products of combustion and the rate of heat absorption. The effects as given in the plat are purely theoretical. In preparing this figure it has been assumed that 1 pound of carbon is burned completely with an air supply varying from the theoretically required amount up. In the computation of the temperatures the heat value of 1 pound of carbon has been taken as 14,500 B. t. u., and the specific heat of the products of combustion was assumed constant at 0.24. The upper curve should be used with the ordinates directly at the left and the abscissas given at the foot of the chart.

[a] Abstracts from Reynold's paper and from Perry's book will be found in Bureau of Mines Bulletin 18, "Heat Transmission into Steam Boilers."

The upper curve indicates that below about 40 pounds of air supply the temperature rises rapidly with each pound of reduction in the air supply; above that the air supply must be reduced considerably to effect a comparatively small rise of temperature.

The lower curve should be used with the ordinates immediately at the left and the abscissas at the bottom of the figure. The abscissas are the temperatures resulting from burning 1 pound of carbon with the various air supplies as given by the ordinates of the upper curve. The ordinates of the lower curve are numbers proportional to the heat imparted by convection to the first elementary length of the dry surface of the heating plate along the path of the gases. The ordinates of the curve are also proportional to the product of the density and the volume of the products of combustion, and the difference of temperatures between the gases and the dry surface of the heating plate. In other words, the ordinates are proportional to H in equation (4). In figuring the values proportional to H the volume of the products of combustion has been used in the equation in place of the velocity, because with any given boiler the two are proportional to each other.

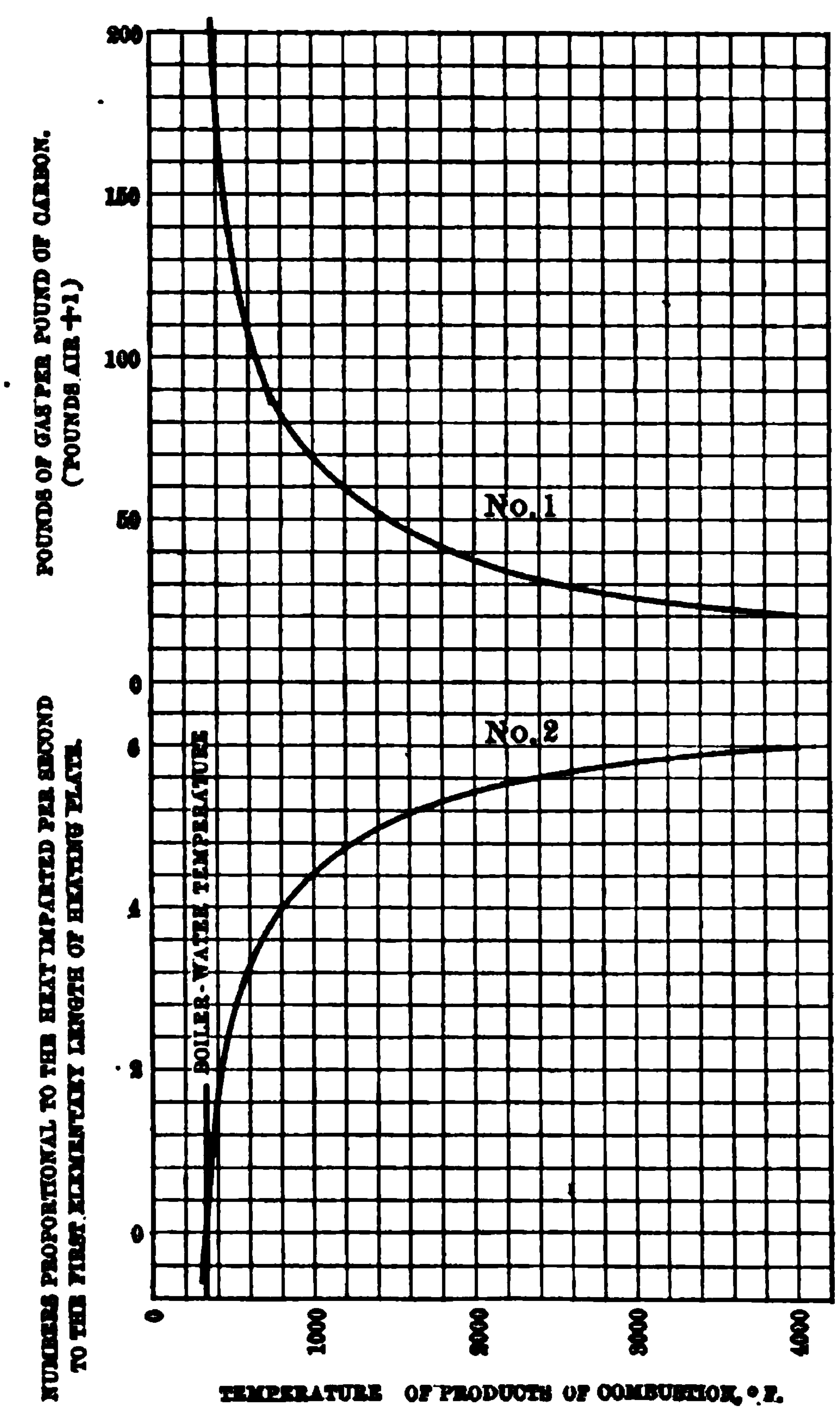


FIGURE 88.—Effect of air supply on the temperature of the products of combustion and the rate of heat absorption. Curve No. 1 shows how the weights of gases resulting from burning 1 pound of carbon with varying air supply affect the temperature of the products of combustion. Curve No. 2 shows how the temperatures resulting from burning 1 pound of carbon with varying air supply affect the rate of heat absorption.

The two curves should be studied together and are useful to compare the probable rates of heat impartation when burning coals with different air supply. Thus, when 1 pound of carbon is burned with 39 pounds of air the resulting weight of the products of combustion is 40 pounds. In the upper curve take the horizontal line of 40 pounds and follow it to its intersection with the curve, then from the intersection follow a vertical line to the scale at the bottom of the chart; this scale gives the temperature of the products of

combustion as 1,800° F. If it is desired to know what quantity of heat is imparted to the first elementary length of the dry surface per unit of time, follow a horizontal line from the point of intersection of the temperature (vertical) line and the lower curve to the scale at the left. For the case under consideration the number proportional to the quantity of heat imparted to the dry surface is 5.3. If 1 pound of carbon is burned with such air supply that the resulting weight of the products of combustion is 24 pounds, the temperature of the gases is 3,900° F. and the number proportional to the quantity of heat imparted to the dry surface of the heating plate is shown to be 6. Although in the latter case the temperature is more than doubled, the volume (density-times-velocity factor in equation (4)) of the gases is so reduced that only about 16 per cent more heat is imparted to the boiler.

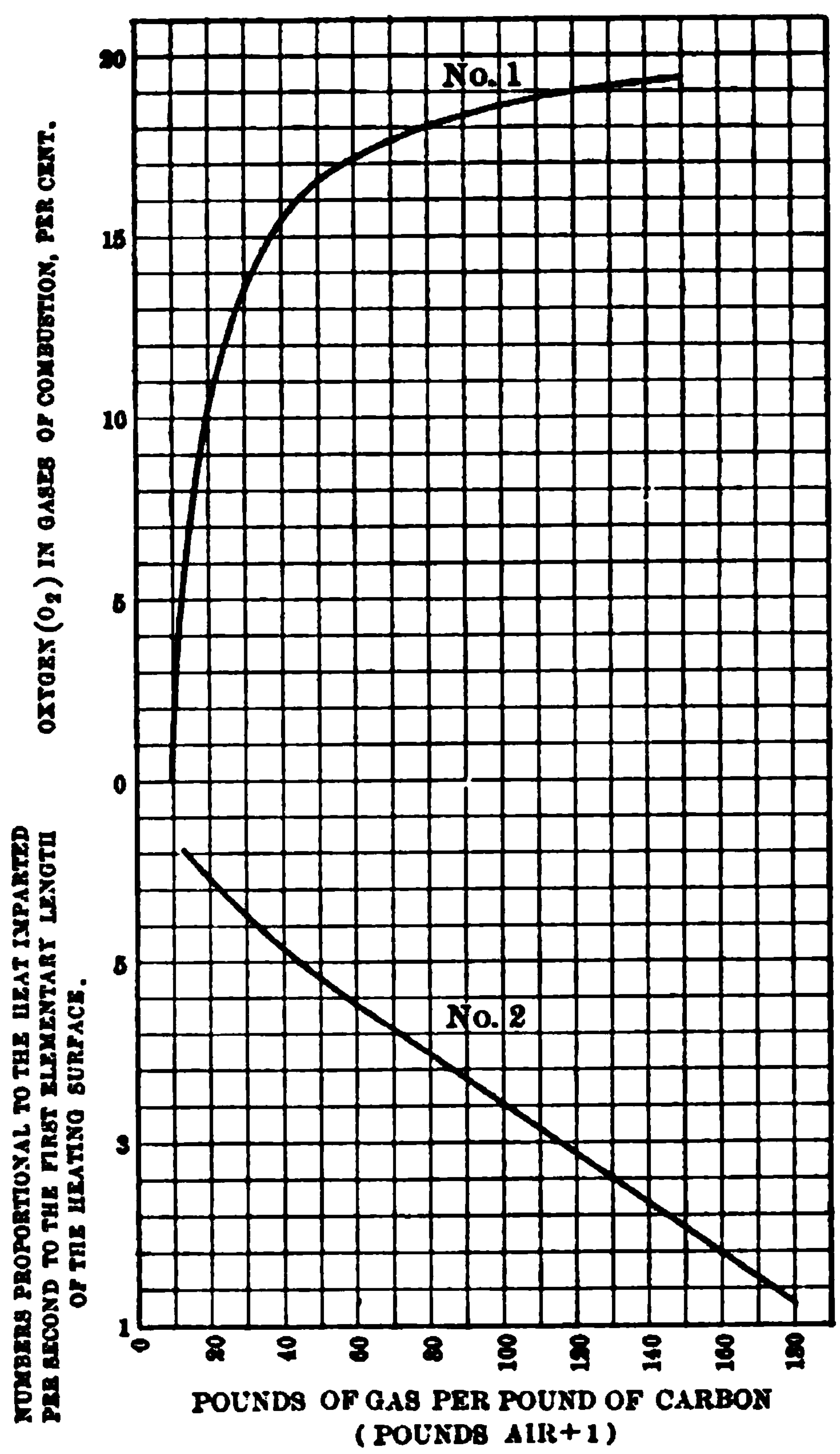


FIGURE 89.—Curve No. 1 shows the percentage of oxygen in the products of combustion and the weights of gases resulting from burning 1 pound of carbon with different air supplies. Curve No. 2 gives the numbers which are proportional to the quantity of heat imparted to the first elementary length of heating plate when burning 1 pound of carbon with different air supplies.

The curves of figure 89 are similar in character to those of figure 88. The upper curve perhaps needs no further explanation. The ordinates of the lower curve are the products of the density and the volume (velocity) of the products of combustion and the temperature difference between the gases and the dry surface of the boiler plate. In other words, the ordinates are the values of H of equation (4) platted against the weight of air supply used to burn 1 pound of carbon. The curve shows directly how the air supply affects the rate of heat impartation by convection to the first elementary length of dry surface. The reader is cautioned not to confuse this rate of heat impartation with the total heat a given boiler would absorb; such values are given on page 356 in connection with figure 91.

Figure 90 is a further exposition of the three factors which affect the rate of heat impartation by convection. In this figure it is shown

how each of the three factors is affected when 1 pound of carbon is burned with various air supplies. The air supplies are expressed as percentages of the amount theoretically required to burn 1 pound of

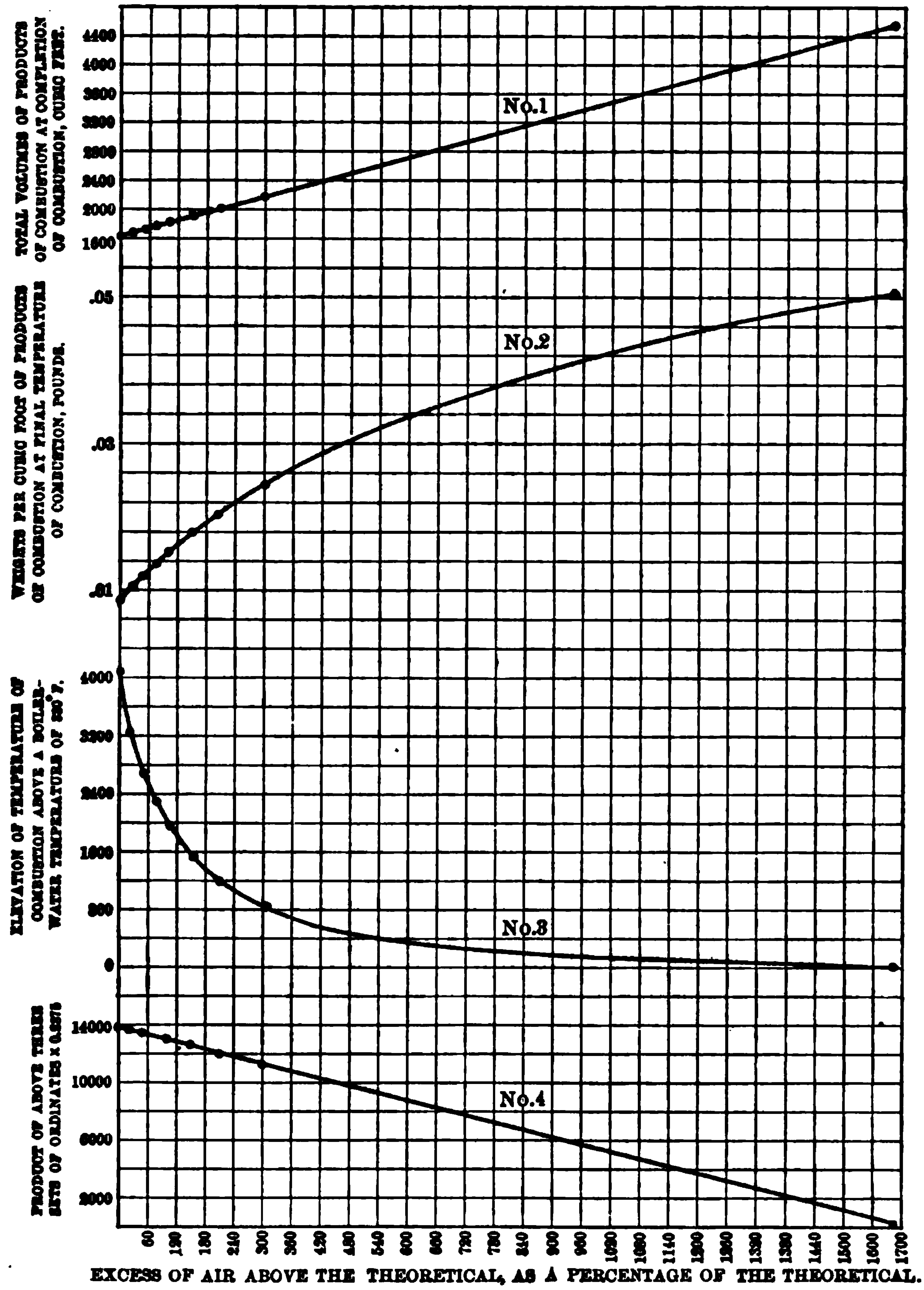


FIGURE 90.—Curves showing the effect of an excess of air on: Total volume of the products of combustion (No. 1); density of the products of combustion (No. 2); the difference between the temperature of the products of combustion and that of the dry surface of the boiler plates (No. 3); the product of the above three items or the rate of heat impartation by convection to the first elementary length of the dry surface (No. 4). The figure is based on the computed results obtained from burning 1 pound of carbon with various excesses of air, the excess being expressed as a percentage of the theoretical amount.

carbon completely. The lowest curve is the product of the three above it. The ordinates of the lowest curve are numbers proportional to the rate of heat absorption by convection by the first ele-

mentary length of dry surface; they are not proportional to the total heat absorbed by a boiler. Attention is called to the fact that the last curve is a straight line. Although the temperature rises very rapidly when the excess of air is reduced beyond 120 per cent, as shown by curve No. 3, the density of the products of combustion, shown in curve No. 2 drops enough to neutralize the gain due to high temperature and the rate of heat absorption remains a straight-line function of the excess of air.

Table 21 gives a method of calculating the relative values of the three factors and the rates of heat absorption by the first elementary length of dry surface of the heating plates. The calculations are made for the combustion of 1 pound of carbon with various excesses of air as indicated in the first horizontal line of the table. The excess is expressed as a percentage of the weight theoretically required to burn 1 pound of carbon. In figuring the temperature of the products of combustion the specific heat of gases was taken constant at 0.237.

The curves of figure 89 were obtained by platting the proper values of Table 21.

TABLE 21.—*Method of calculating relative rates of heat absorption by a hypothetical boiler.*

1. Excess of air (per cent)	0	25	50	75	100	150	200	300	1,604
2. Pounds of O_2 per pound of carbon	2.67	3.33	4.00	4.67	5.33	6.67	8.00	10.67	45.43
3. Pounds of air per pound of carbon (4 parts N, 1 part O)	13.33	16.67	20.00	23.33	26.67	33.33	40.00	53.33	227.15
4. Specific heat of products of combustion at constant pressure	0.2370	0.2370	0.2370	0.2370	0.2370	0.2370	0.2370	0.2370	0.2370
5. Temperature rise due to combustion [a] (°F.)	4,299	3,486	2,933	2,532	2,226	1,794	1,503	1,134	270
6. Temperature rise+50 [b] (°F.)	4,349	3,536	2,983	2,582	2,276	1,844	1,553	1,184	320
7. Absolute temperature of combustion (°F.)	4,810	3,997	3,444	3,043	2,737	2,305	2,014	1,645	781
8. Relative volume of unit mass of gases at absolute temperature of combustion when volume at 461° F. absolute=1	10.43	8.67	7.47	6.60	5.94	5.00	4.37	3.57	1.69
9. Relative total volumes of products of combustion, each at its final temperature of combustion [c]	139.1	144.5	149.4	154.0	158.3	166.65	174.8	190.3	384.8
Elevation of temperature of combustion above steam temperature—									
10. At 320° F., 75 pounds on gage (°F.)	4,029	3,216	2,663	2,262	1,956	1,524	1,233	864	0
11. At 390° F., 205 pounds on gage (°F.)	3,959	3,146	2,593	2,192	1,886	1,454	1,163	794	0
12. Density of products of combustion, each at its final temperature of combustion when density at 320° F.=1 [d]	0.1624	0.1956	0.2268	0.2567	0.2853	0.3388	0.3878	0.4748	1
13. H [e]	910	909	902	894	883	861	836	781	0

[a] Equals $\frac{14{,}600}{C_p\ (\text{pounds of air}+1)}$ where C_p is the specific heat of the gas at constant pressure.

[b] Atmospheric temperature=50° F.

[c] Equals item 3 × item 8.

[d] This density refers to number of molecules in a unit volume and not to their composition.

[e] H is merely a number proportional to the heat absorbed. It equals item 9 × item 10 × item 12.

TOTAL HEAT IMPARTED BY CONVECTION ALONG THE FULL LENGTH OF THE PATH OF GASES.

So far the effect of air supply on the rate of heat impartation to the first elementary length of dry surface along the path of the gases has been considered. As the gases flow over the dry surface and impart heat to it their temperature gradually drops, their density increases, and their velocity decreases if the cross-section of the gas passage remains the same. The change in these three factors continually changes the rate of heat impartation to the plates of the

boiler. If one wishes to compute the total heat imparted to the dry surface of the entire length of the gas path, equation (4), $H = Cqv(T-t)$, can be applied successively to small lengths of the dry surface along the the path of the gases. These lengths should be of such magnitude that the variation of the three factors within these small lengths would be small and could be neglected. The portions of heat absorbed by each small length of the dry surface can be added and the total heat imparted to the heating plates of the boiler thus obtained. To illustrate this method let a specific example be used.

Assume a given boiler consists of a single flue 0.1 foot in diameter and 10 feet long, and is operated at a steam pressure corresponding to a steam temperature of 320° F. This boiler is fed with the products of combustion resulting from burning 1 pound of carbon per hour with a 25 per cent excess of air. These conditions are the same as those given in the second vertical column of figures in Table 21. The value of B in equation (4) can be assumed as 0.127, this value, when used with relative velocities and the relative density of the products of combustion, and when the unit of surface is expressed in square feet, will agree fairly well with the actual results. Let the length of the flue be divided into twenty parts each 0.5 foot long and having 0.157 square foot of area. In this calculation let the specific heat be 0.237 and constant for all temperatures.

Thus, from Table 21 there is obtained

$$(T-t) = 3{,}216, \qquad q = 0.1956, \qquad v = 144.5.$$

Then the heat imparted per hour to the first length of the tube is

$$H = 0.127 \times 0.157 \times 3{,}216 \times 0.1956 \times 144.5 = 1{,}812 \text{ B. t. u.}$$

The absorption of the above quantity of heat from the gases reduces their temperature by

$$\frac{1{,}812}{17.67 \times 0.237} = 433^\circ \text{ F.}$$

The three factors at the entrance to the second 0.5-foot length of the flue are

$$(T - t) = 3{,}216 - 433 = 2{,}783^\circ \text{ F.}$$

$$q = 0.1{,}956 \times \frac{(3{,}216 + 780)}{(2{,}783 + 780)} = .2194$$

$$v = 144.5 \times \frac{(2{,}783 + 780)}{(3{,}216 + 780)} = 128.8$$

In the last two equations the absolute temperature of the gases is obtained by adding to the factor $(T - t)$ the absolute temperature of steam, which is 780° F.

The heat imparted to the second portion of the length of the flue is

$$H = 0.127 \times 0.157 \times 2{,}782 \times 0.1956 \times \left(\frac{3{,}216 + 780}{2{,}783 + 780}\right) \times 144.5 \times \left(\frac{2{,}783 + 780}{3{,}216 + 780}\right) = 1{,}568 \text{ B. t. u.}$$

It will be seen that the two factors in parentheses, being reciprocals, drop out and the heat imparted to any 0.5-foot length of the tube will be proportional to the factor $(T-t)$ alone.

In Table 22 are given the three factors at the entrance of the gases to each 0.5-foot length of the tube, and the quantity of heat absorbed by each length, the values having been computed as outlined above.

Figure 91 shows graphically how the three factors vary with the length of the tube. The curves have been platted from the values in Table 22.

TABLE 22.—*Heat impartation along a hypothetical boiler tube, by sections.*

Half-foot sections.	Difference in temperature of gas and boiler (°F.).	Relative velocity.	Relative density.	Partial heat imparted to heating plate per hour. $H=Cqv.(T-t.)$.
First	3,216	144.5	.1956	1,812
Second	2,783	128.8	.2194	1,568
Third	2,408	115.3	.2451	1,356
Fourth	2,084	103.6	.2728	1,174
Fifth	1,804	93.5	.3024	1,017
Sixth	1,561	84.7	.3338	880
Seventh	1,351	77.1	.3667	762
Eighth	1,169	70.5	.4009	659
Ninth	1,012	64.8	.4360	570
Tenth	876	59.9	.4718	494
Eleventh	758	55.6	.5080	427
Twelfth	656	51.9	.5441	369
Thirteenth	568	48.7	.5796	320
Fourteenth	492	46.0	.6142	277
Fifteenth	426	43.6	.6478	240
Sixteenth	369	41.5	.6799	208
Seventeenth	319	39.7	.7108	179
Eighteenth	276	38.1	.7397	155
Nineteenth	239	36.8	.7666	134
Twentieth	207	35.6	.7915	116
Total for 10 feet				12,717
Final temperature above steam (°F.)	179			

The arithmetical method of finding the temperature drop along any part of the gas path is slow and laborious. More accurate results can be obtained with less labor by the use of calculus. This can be done as follows:

In the equation

$$H=Cqv\ (T-t) \tag{4}$$

Let $(T-t)=\theta$

Inasmuch as q varies inversely and v directly as the absolute temperature of the gases, both can be expressed as functions of the temperature, thus:

$$q=\frac{C'}{T}$$

$$v=C''T$$

where T = absolute temperature of the gases and C' and C'' are constants. The velocity varies also directly as the quantity or the

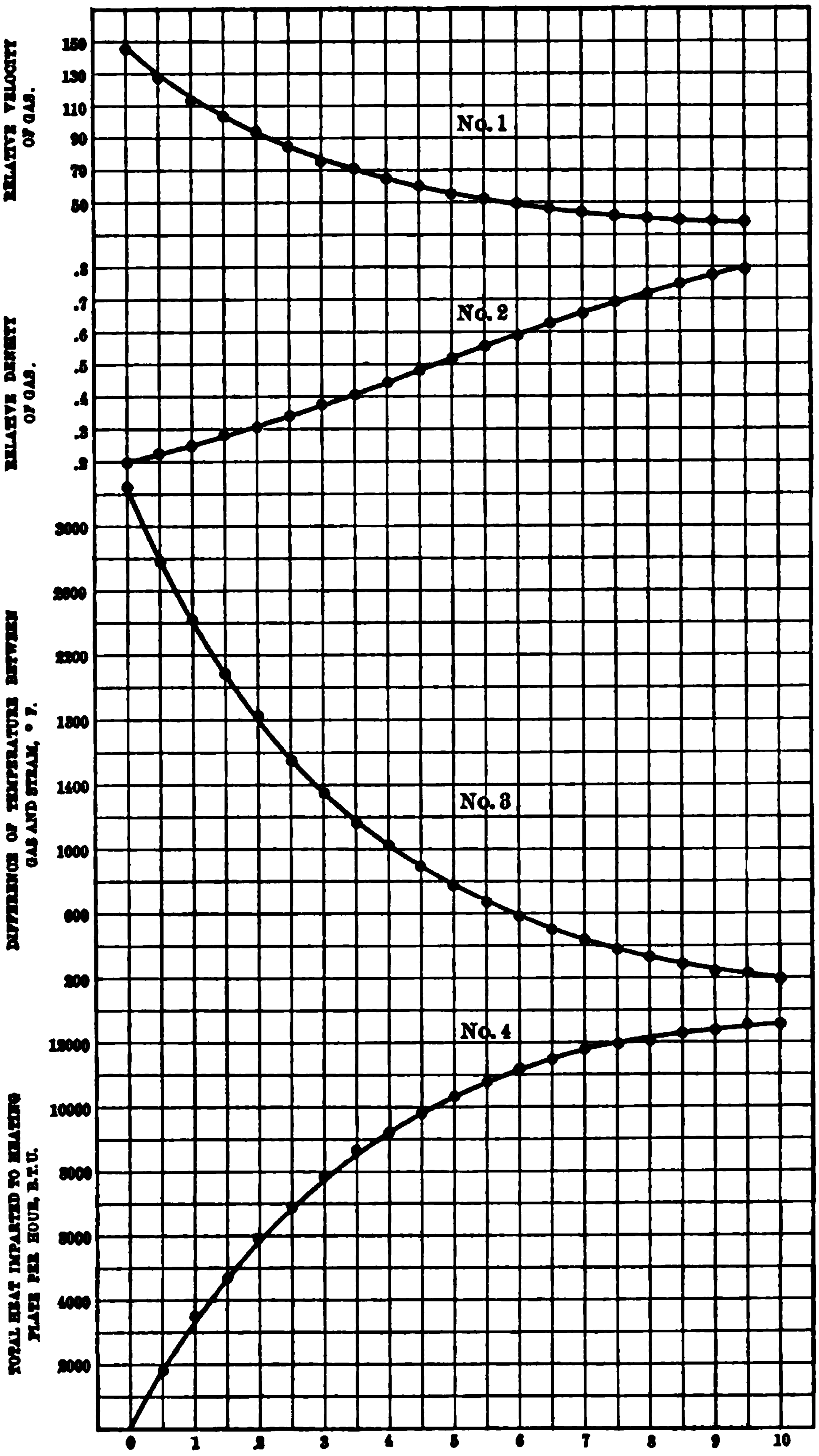


FIGURE 91.—Curves showing rate of impartation of heat by convection to a boiler flue 10 feet long and 0.1 foot in diameter.

weight of the gases and inversely as the cross-sectional area of the gas passage. For cylindrical passages the velocity varies as the

square of the diameter. Therefore if M is the weight of gases passing through the passage per second, and D is the diameter of the passage, the velocity is expressed by the equation

$$v=\frac{\mathrm{KTM}}{\mathrm{D}^2}$$

in which K is a new constant.

Equation (4) then reduces to

$$\mathrm{H}=\frac{\mathrm{CM}\theta}{\mathrm{D}^2}.$$

Hence in a short length dx of a cylindrical gas passage the heat transmitted to the boiler is

$$-\mathrm{C}_p\mathrm{M}d\theta=\frac{\mathrm{CM}\theta}{\mathrm{D}^2}\times \mathrm{D}\pi dx=\frac{a\mathrm{M}\theta}{\mathrm{D}}dx$$

or,

$$\frac{d\theta}{\theta}=-\frac{bdx}{\mathrm{D}}. \tag{5}$$

C, a and b are different constants, each successive one combining two or three others during the course of transformations. The symbol C_p stands for specific heat of gas at constant pressure.

Integrating equation (5), one has

$$\log_e\theta=-\frac{cx}{\mathrm{D}}+\mathrm{K},$$

where K is a constant of integration.

When $x=\mathrm{O}$, $\quad \mathrm{K}=\log_e\theta_o$

When $x=l$, $\quad \log_e\theta_l=\frac{cl}{\mathrm{D}}+\log_e\theta_o$

$$\frac{\theta_1}{\theta_o}=e^{-\frac{cl}{\mathrm{D}}}$$

Therefore, $\theta_1=\theta_o e^{-\frac{cl}{\mathrm{D}}}$ (6)

In equation (6) θ_1 is the elevation of the temperature of the gases at any point l in the cylindrical gas passage above the temperature of the dry surface, θ_0 is the initial temperature elevation of the gases when they enter the flue, e is the base of the natural logarithm system and is equal to 2.718, c is a constant depending on the design and the condition of the boiler, l is any point along the length of the flue, and D is the diameter of the flue. With any one given boiler c would have to be determined experimentally. With c once determined the temperature of the gases at any point of the flue can be computed by substituting the distance of the point from the entrance end of the flue for l in equation (6).

According to equation (6) the heat imparted to the dry surface of the flue is

$$C_pM\theta_o\,(1-e^{-\frac{cl}{D}})$$

and the heat available for absorption is

$$C_pM\theta_o.$$

Therefore the true efficiency of the boiler is

$$E=1-e^{-\frac{cl}{D}} \tag{7}$$

Equation (7) states that the true boiler efficiency is independent of the initial temperature, and independent of the weight of gases passing through, increases when the length of the gas path increases, and decreases when the diameter of the flue increases. It should be remembered that equation (4), from which equation (7) has been derived, is only an approximate one, and that there are modifying factors entering into the process of heat transfer from the gases to the metal plate. On the whole, however, when the velocity of the gases is fairly high equation (7) comes very near to the actual facts for a considerable range of the velocity.

The results of the laboratory experiments made on small multitubular boilers and outlined in the preceding section of this bulletin show that as far as heat impartation by convection is concerned the true boiler efficiency is independent of the initial temperature of the gases. The experiments further show that the true boiler efficiency is nearly independent of the weight of gases passing through the boiler. The last statement has been found true also in tests made with a torpedo-boat boiler, the results of which are given in the preceding chapter. Figure 92 shows that the true boiler efficiency obtained on the tests just referred to is constant within about 4 per cent, although the weight of the gases passing through the boiler is more than tripled. The true boiler efficiency has been computed from the furnace temperature, the flue-gas temperature, and the temperature of the steam in the boiler, according to the following equation:

$$\text{True boiler efficiency}=\frac{\text{temperature in furnace}-\text{temperature of flue gases}}{\text{temperature in furnace}-\text{temperature of steam.}}$$

In the figure the true boiler efficiency is platted against the weight of the coal fired per hour per square foot of grate area. This item has been taken because it is directly proportional to the weight of gases passing through the boiler.

That long gas passages are more efficient than short ones of the same cross section will perhaps be generally admitted. Often the gas passages in commercial boilers can be lengthened by baffling the boiler in such a way that the heating plates are put in series with

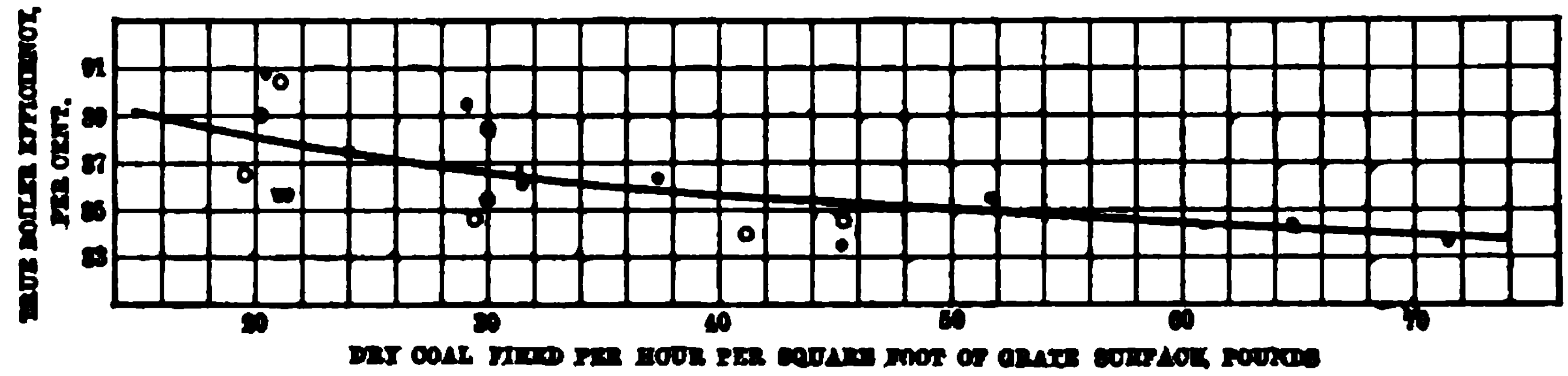


FIGURE 92.—Curve showing the relation of true boiler efficiency to the weight of dry coal fired per hour per square foot of grate area. Tests made on Normand boiler of the U. S. torpedo boat *Biddle*. Hollow circles represent tests made with run-of-mine coal; round dots represent tests made with small briquets; rectangular dot represents test made with large briquets.

each other with respect to the gas path. A more detailed discussion of this feature is given in Bureau of Mines Bulletin No. 18, entitled "Heat Transmission into Steam Boilers" (now in course of publication.)

The fact that gas passages of smaller cross section are more efficient than larger ones of the same length may perhaps be doubted on the ground that the larger gas passage contains more heating surface. The feature that makes the small gas passages more efficient than the larger ones is the fact that in the case of small gas passages the heat-giving medium, the gas, and the heat-receiving medium are brought closer together, and consequently the path of the heat is shorter and the exchange of heat takes place in proportionately less time. The following illustration may be useful in making clear the above explanation.

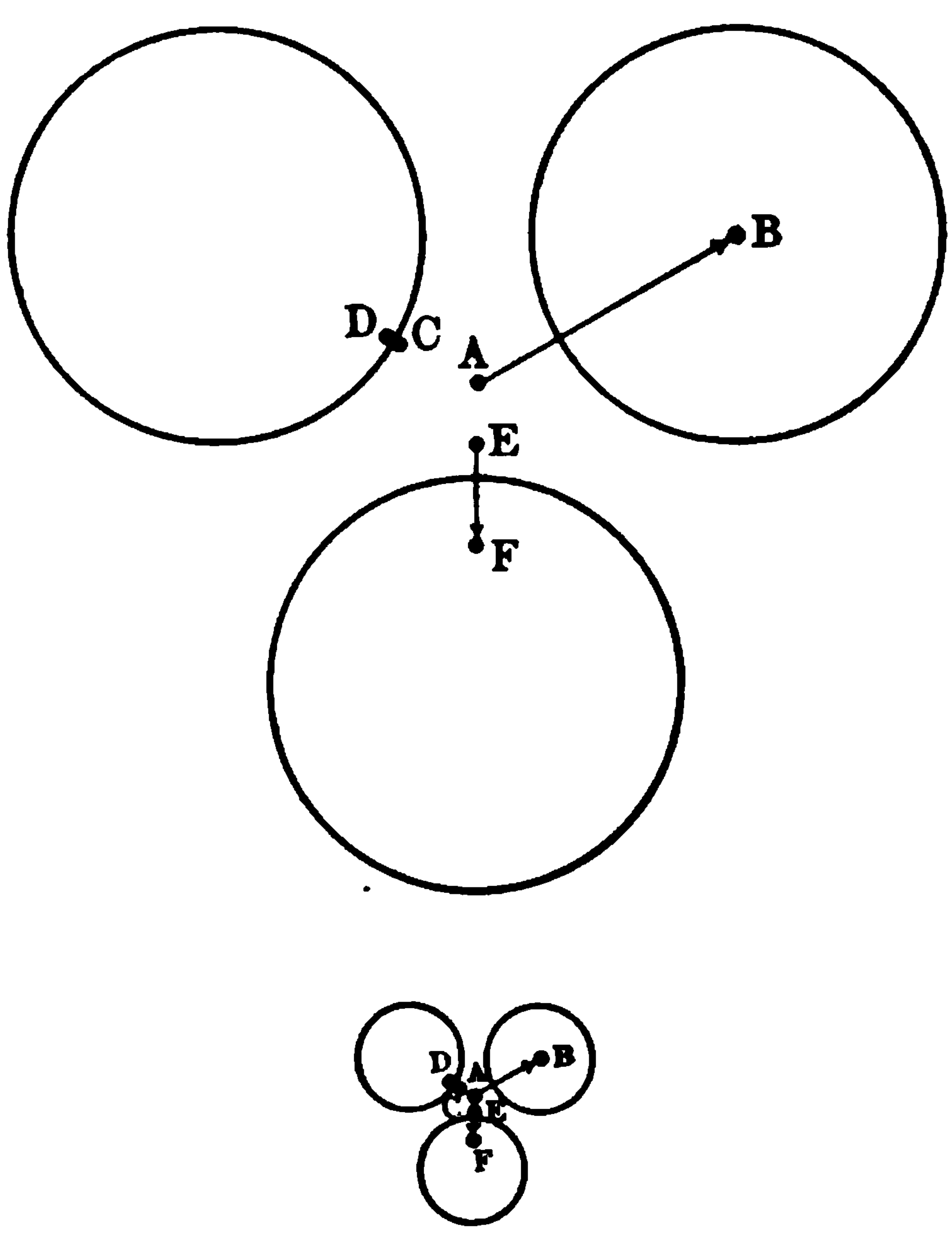


FIGURE 93.—Diagram showing the average distance of heat travel in two sets of boiler tubes of different size.

In figure 92 are shown the cross section of two groups of boiler tubes. In the lower group all the dimensions are exactly one-fourth of the upper group. The heat travels from the gas outside the tubes into the water on the inside of the tubes. The longest path for the heat to travel is from the center of the gas space to the center of the tubes, or from A to B. The shortest path is from the dry

surface of the tube to the wet surface, or from C to D. The average length of the heat path is approximately from E to F. Now, it is easy to see that this average length of the heat path is much shorter (only one-fourth as long) in the small tubes than in the large ones. It seems strange that in the past boiler men have been considering only a part of this heat path, that through the metal, which was the easiest part of the path, while the most tortuous part, that through the gas itself, was always neglected. The axiom in designing efficient boilers is to bring the gas and the water as close together as practicable, above all, to reduce the path through the gas. An ideal case for rapid heat transmission would be to bubble the hot gas through the water in very fine jets; in such a case the heat would be exchanged almost immediately.

PRINCIPLES INVOLVED IN THE MOVEMENT OF GASES THROUGH STEAM-GENERATING APPARATUS.

The movement of gases through the steam-generating apparatus is an essential factor in the production of steam. The air is caused to flow into the furnace through the grate and through the openings in the fire doors. This movement of the air brings to the burning fuel the oxygen necessary for the combustion. The gaseous products of combustion absorb the heat that is developed by the burning of the fuel and carry it to the heating plates of the boiler. After the boiler has absorbed most of the heat from the gas the latter flows out through the stack. Thus the movement of the gases serves as a conveyer which supplies the fuel with the oxygen and carries the heat developed by the combustion to the heating surfaces of the boiler. After most of the heat has been absorbed the products of combustion are ejected through the stack.

Gas flows only from a place of higher pressure to a place of lower pressure, just as water flows from a place of higher level to a place of lower level. In the case of the steam-generating apparatus the gas flows through the furnace and boiler into the stack because the pressure in the stack is lower than that of the outside atmosphere. It takes its course through the furnace and the boiler because every other passage is usually prevented. The pressure in the stack can be reduced either by the use of a high stack or by an exhaust fan. The latter method of producing pressure difference is known as induced draft; it is used in most of the large power-plant installations. The same movement of gases can be obtained if the pressure at the base of the stack is maintained at atmospheric pressure, and the pressure under the grate or in the firing room is raised above that of the atmosphere. This method of producing pressure difference is known as forced draft, and is largely employed in the boiler plants of steamships. There is no fundamental difference between

the induced and the forced draft. In any case when the temperature and the resistance to the passage of the gases remain constant the velocity of the flow depends on the difference of the pressure at the front of the boiler and the base of the stack. There is no pulling or suction in the movement of gases, only pushing. If one stops to think that gas is a discontinuous substance he will admit this fact. To claim that the chimney or the exhaust fan pulls or sucks the gases out of the boiler setting would be as sensible as to claim that in the case of a condensing steam engine the condenser sucks the piston through the latter part of the stroke.

The high chimney is the most common means of producing difference in pressures. The reduction in pressure at the base of the stack depends on the height of the latter and on the temperature difference of the column of gases inside of the stack and a column of outside air of the same dimensions. It is due to the fact that gases expand when heated, in consequence of which the chimney contains a smaller weight of gases than a similar column of air at outside temperature. The column of hot gases inside of the chimney presses by its weight against the gases in the uptake of the boiler setting, and a column of air of the same dimensions and at atmospheric temperature presses with its weight against the gases in the ash pit and the furnace. As a result of this difference of pressure the outside air pushes the furnace gases into the chimney and through it into the open air. Thus the heat left in the escaping gases is not entirely wasted, as part of it is utilized in keeping up the continuous current of gases flowing through the furnace and boiler. However, the part of the waste heat thus utilized is only about 4 per cent of the total heat rejected through the stack.

With an exhaust fan between the uptake and the stack, the pressure anywhere in the boiler setting is below that of the atmosphere and is lowest at the edges of the blades next to the shaft. With a pressure fan applied to the ash pit or fire room the pressure under the grate or in the fire room is always above that of the atmosphere. At the top of the stack the pressure is always about equal to that of the atmosphere at that elevation. At the base of the stack the pressure is sometimes above and sometimes below the atmospheric pressure at that particular elevation, but it is always higher than the pressure at the top of the stack. The atmospheric pressure at the base of the stack is higher than that at the top of the stack by the weight of an air column equal in height to the chimney.

In practice the pressures of the gases in the various parts of a boiler setting are measured with instruments called draft gages. The pressures are usually expressed in inches of water. One inch of water means a pressure sufficient to support a column of water 1 inch high. The zero points are, or should be, the atmospheric pressure at the elevation of the boiler room.

The pressure drops gradually along the path of the gases from the ash pit to the uptake. The pressure drop from one point of the boiler setting to another varies with the resistance that the part of the path between the two points offers to the flow of gas. In the present state of meager knowledge of this resistance and in entire absence of adequate definition of a unit of this resistance, a statement of the exact relation between the pressure drop and the resistance can not be made. It can only be said that a high pressure drop from the ash pit to the furnace means a high resistance of the fuel bed, or a high pressure drop from the furnace to the uptake signifies that the gases meet high resistance when passing through the boiler. This law, which in some respects is similar to Ohm's law as applied to problems involving electrical resistance of conductors, may be stated as follows:

(*a*) If the total pressure drop from the ash pit to the uptake remains constant, the pressure drop through any portion of the gas path varies with the resistance to the flow of the gases, although the relation may not be a simple proportion. Thus, suppose the total pressure drop is 1 inch of water and the drop through the fuel bed is 0.5 inch, if the total pressure drop is kept the same but the resistance through the fuel bed is increased by doubling its thickness, the pressure drop through the fuel bed will increase to about 0.66 inch of water; or, if for the same total drop the resistance of the fuel bed is increased by quadrupling the thickness, the pressure drop through the fuel bed will increase to about 0.8 inch of water.[a]

(*b*) When the resistance through any portion of the gas path remains constant, the weight of gas passing through this portion is approximately proportional to the square root of the pressure drops through this portion, provided that the temperature remains nearly constant.

With any one boiler the resistance to the flow of gas from over the fire to the uptake is very nearly constant, so that one may say that the weight of gases passing through the boiler setting is approximately proportional to the square root of the pressure drop from over the fire to the uptake. For example, if in case (A) the pressure drop from the furnace to the uptake is 0.25 inch, in case (B) 1.0 inch and in case (C) 4.0 inches of water, the weight of gases passing through the boiler in the three cases will be proportional to $\sqrt{0.25}=0.5$, $\sqrt{1.0}=1$, and $\sqrt{4.0}=2$, respectively; that is, in case (B) the weight of gases passing through the boiler will be twice that in case (A) and one-half of that in case (C). Of course this is approximately true only if the temperature of the gases remains about the same.

[a] The values 0.66 and 0.8 are obtained by deduction from experiments with shot, described in Bureau of Mines Bulletin 21.

Ordinarily the resistance of the fuel bed, particularly in the case of a hand-fired furnace, may vary considerably in a short interval of time, and as stated under (*a*) the pressure drop through the fuel bed varies correspondingly. Therefore, an increased weight of gas flowing through the fires and an increase in the rate of combustion will not generally follow an increase in the pressure drop through the fuel bed. On the contrary, the weight of gases and the rate of combustion may decrease on account of the increased resistance in the fuel bed. The causes of increased resistance in the fuel bed may be fine coal, accumulated clinker, or fused coal.

(*c*) If the resistence to the flow of gases remains constant, the pressure drop through any portion of the path of gases will have a constant ratio to the total drop from ash pit to uptake. Thus, for example, if the pressure drop from over the fuel bed to the uptake is 0.5 inch of water when the total pressure drop from ash pit to uptake is 1 inch, it will be 1 inch if the total drop is increased to 2 inches, and 2 inches if the total drop is increased to 4 inches of water.

(*d*) If the fuel bed is doubled in thickness, its resistance to the flow of gas is increased in such a way that to force the same weight of gas through it the pressure drop must be doubled; or, if the thickness of the fuel bed is quadrupled the pressure drop must be about quadrupled in order that the same weight of gas be pushed through as with the single thickness. Of course this law assumes that other conditions of the fuel bed as well as the temperature remain constant. Similarly if the length of the gas path through the boiler is doubled (without making any changes in its cross section or increasing the bends beyond a proportionate number) the pressure drop through it must be doubled if the same weight of gas is to be forced through; or if the length is quadrupled the pressure must also be quadrupled to pass as much gas through as with the single length. The condition of this law is that the cross-sectional area be not changed nor the number of bends in the gas path be increased beyond the proportionate number.[a]

This is an important law, and should be given full consideration in cases where change in baffling is contemplated or where it is desired to increase the rate of combustion without means to increase the total pressure drop. Thus suppose in a plant where the total pressure drop available is 1 inch of water, the thickness of fuel bed at 100 per cent capacity is 12 inches. Suppose that with this thickness of fuel bed the pressure drop through the bed is 0.6 inch and through the boiler proper 0.4 inch. Suppose further that it is required to increase the capacity by 25 per cent and the total pressure drop can not be increased. This condition requires that the rate of combustion and

[a] These laws are deduced from experiments with shot and with small multitubular boilers. Details of these experiments are found in Bulletin 21 of the Bureau of Mines; also in Bulletin 18, now in course of publication.

the weight of gases pushed through the furnace and boiler be increased by 25 per cent. To push through this increased weight of gas, the resistance to its flow must be reduced, which must be accomplished by reducing the thickness of the fuel bed. The resistance through the boiler proper can not be varied without radical changes in the boiler setting. To push 25 per cent more gas through the boiler proper requires, according to the law under (*b*), 1.25^2 times greater pressure drop than at normal capacity. Therefore the pressure drop from over the fuel bed to the uptake must be

$$1.25^2 \times 0.4 = 0.6 \text{ (nearly)}.$$

The available pressure drop through the fuel bed is then $1-0.6=0.4$ inches of water. To push 25 per cent more gas through the fuel bed with 0.4 inch of pressure drop, the thickness must be reduced to

$$\frac{12 \times 0.4}{0.6 \times 1.25^2} = 5.1 \text{ inches}.$$

The above example is presented to illustrate the principle and to show what reduction of the thickness of fuel bed may bring about. Some firemen have the idea that to reduce the air supply they must carry a heavy fuel bed. This is wrong. The gas analyses given in Table 7 and the discussion in connection with it show that very little free oxygen passes through the fuel bed. Large excesses of air usually enter the furnace through holes in the fuel bed, through the furnace doors, and through leaks in the setting.

The law under (*d*) may be useful in predetermining the effect upon the rate of combustion when increasing the length of the path of gases over the heating plates of a boiler and of making other changes in the arrangement of the heating plate of a boiler.

The reader should bear in mind that all of the four laws are true at constant temperature. When the temperature changes, some slight modifications are necessary.

THE WORK DONE BY PUSHING GASES THROUGH THE FURNACE AND BOILER.

The work done by pushing the gases through the steam-generating apparatus is equal to the volume of gas displaced times the pressure against which the volume of gas is displaced. If the volume is expressed in cubic feet per second and the pressure in pounds per square foot, the product is the work done per second in foot-pounds (the volume of the gas should always be reduced to atmospheric temperature).

The following example shows a method of computing the work done in pushing the gases through a boiler setting:

A battery of boilers developing 1,000 boiler horsepower burns 4,000 pounds of coal per hour with the average air supply of 15 pounds per pound of coal. The battery is operated with an average pressure drop from the ash pit to the uptake of 1 inch of water. A pound of air at atmospheric temperature occupies a volume of about 13 cubic feet. This figure makes the total volume of gas pushed through the boilers per second equal to

$$\frac{4{,}000 \times 15 \times 13}{60 \times 60} = 217 \text{ cubic feet.}$$

The pressure of 1 inch of water is equivalent to a pressure of 5 pounds per square foot, so that the work done per second in pushing the gases through the boiler setting is

$$217 \times 5 = 1{,}085 \text{ foot-pounds, or}$$

$$\frac{1{,}085}{550} = 1.97 \text{ horsepower.}$$

The last figure is surprisingly small, but it is perhaps larger than the power actually used in practice. It is true that in mechanical-draft installations the power required to drive the fans is much larger than the preceding figure indicates, but this large amount of power is due to inefficient fans, long, narrow air ducts (often containing many sharp turns), and perhaps a large percentage of leakage. It may be stated that the efficiency of the fans used for producing drafts runs between 5 and 50 per cent; many fans have an efficiency much nearer to 5 than to 50 per cent. These inefficient fans are the result of the demand for cheap machinery. In the past such demands were entirely excusable; nobody wanted to pay a high price for an efficient fan to save 1 per cent or less of steam; for even if the fans consumed 10 times as much energy as was really required to push the gases through the boiler setting the amount of steam used for that purpose would be less than 2 per cent.

The capacity of a boiler is increased by pushing over its heating plates a larger weight of gases. Thus, to double the capacity the weight of gases must be about doubled; to triple the capacity the weight of gases must be tripled, and so on. The power required to push the gases through the boiler increases much faster than the weight of the gases or the capacity of the boiler. This increase in the power is rapid because both the volume of gases and the pressure against which the gas is pushed increase. Moreover, the pressure increases as the square of the weight of gases to be pushed through, so that the work put on the fan increases approximately as the cube of the capacity. Thus, doubling the capacity of the battery of boilers previously referred to would increase the work put on the fan eight times, and tripling the capacity would increase the load on the fan 27 times that at

normal capacity, and so on. The power actually needed to push the gases through the furnace and the boiler, even with this large increase, would be so small that quadrupling the capacity of the battery of boilers appears entirely feasible and practicable, particularly so in large power plants where power from steam is derived by large steam-turbine units and where efficient fans driven with electric motors could be employed. The reduction in the first cost of a power plant due to a smaller number of boilers would be a very large item and very much in favor of operating boilers at high capacity.

RELATION OF PRESSURE DROP TO RATE OF COMBUSTION AND EVAPORATION.

Since for any one steam-generating apparatus the resistance to the flow of gas between the furnace and the uptake is practically constant, it is reasonable to expect that for a greater difference in pressures between these two places a greater weight of gases will pass through the boiler, provided that the temperature of the gases remains unchanged. The passage of a greater weight of gases is the result of a higher rate of combustion and the cause of a more rapid production of steam. Thus, one may logically conclude that the rate of combustion and the capacity of the boiler will vary with the difference of pressures between the furnace and the uptake.

The resistance which the fuel bed offers to the flow of air varies with the thickness of the fire, the size of the coal, and the nature and quantity of the ash on the grate. It would be hardly reasonable to expect an increased rate of combustion and higher capacity when one or more of these factors increases the resistance of the fuel bed, although the pressure drop through the fuel bed may be increased.

The resistance of the grate is constant and should be small, because the energy required to move air through it is uselessly expended. It follows, then, that the percentage of air spaces in the grate should be as high as mechanical construction and factor of safety allow. The pressure drop through the grate alone should be as nearly zero as possible. The power applied to the fans should be utilized as completely as practicable in two ways only—(*a*) in scrubbing ashes and products of combustion off the solid pieces of fuel, and (*b*) in scrubbing the soot and cooled gases off the water-heating surface.

SIGNIFICANCE OF DRAFT OVER THE FUEL BED.

A draft gage connected to the space above the fuel bed gives useful information as to the condition of the fire to a fireman who understands the significance of its indications. Thus, after cleaning a fire, if the pressure drop from ash pit to fuel bed is too small, the fireman may be sure that there are holes in the fire, or that it is too thin; or, if the pressure drop is too great, it is probable that the fire is

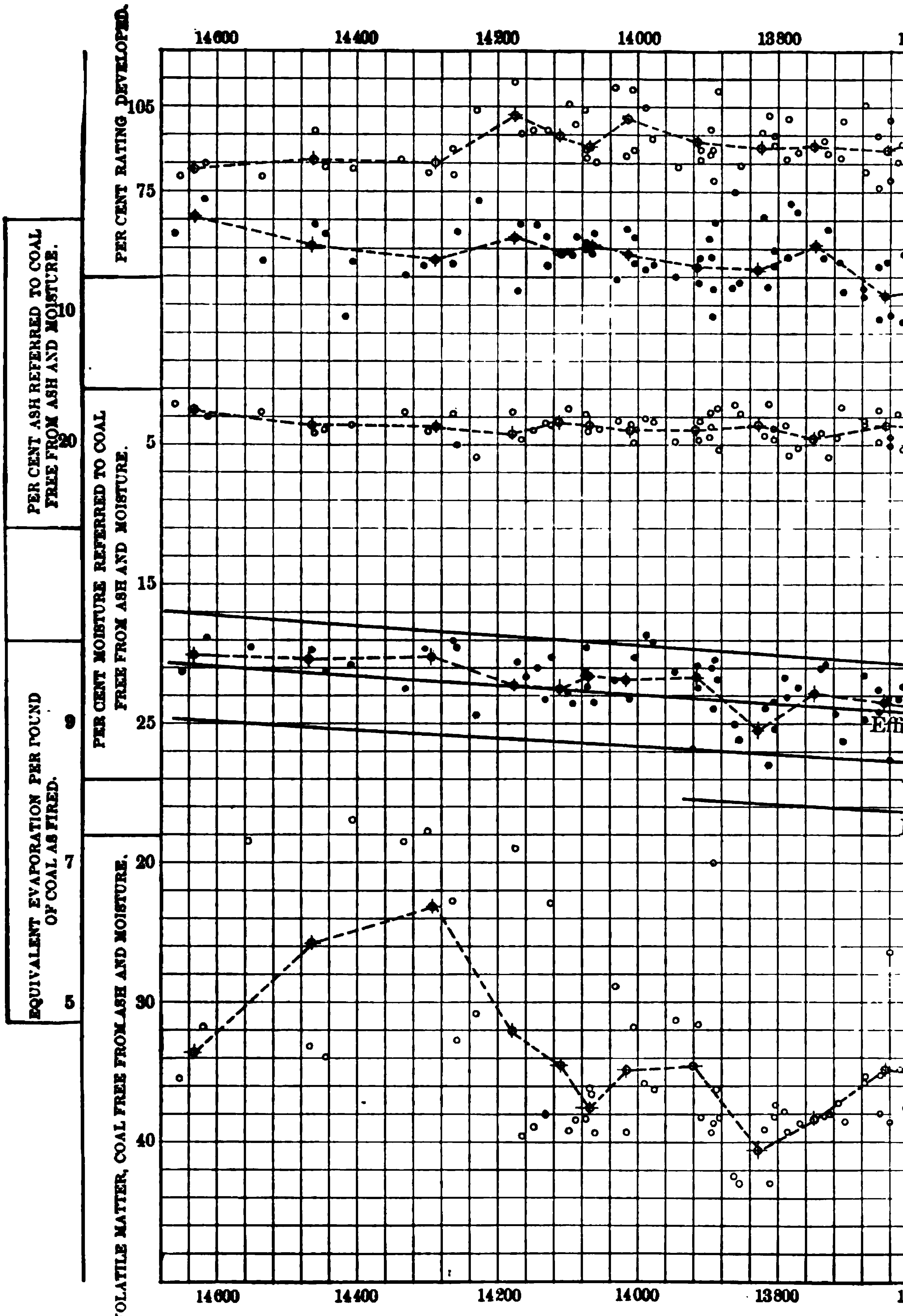
too thick. A gradual increase of the drop through the fuel bed after a fire has burned for some time (in case of hand firing especially), is an indication of the accumulation of clinker next to the grate. Of course, a drop through the fuel bed is adjudged high or low only after considering it in connection with the total drop through the whole apparatus. It may happen, in the same apparatus, with the same coal from the same bin, and the same total pressure drop, that much less coal is burned and a smaller amount of steam produced in one day than on another, although the pressure drop through the fuel bed is higher on the day of the lower steam production. The fireman may wonder why that is. The explanation may be drawn from the preceding paragraphs, as follows: When coal is taken out of the side and bottom of a bin, the larger pieces tend to flow out first, leaving the smaller pieces and dust in the far corners until all the coarser coal has been burned. When burning the finer coal, the resistance to the passage of air through the fuel bed is greater, and this greater resistance causes a higher pressure drop; that is, a higher draft above the fire. Simultaneously a smaller air supply results in a lower rate of combustion and a smaller steam production.

THE STEAMING VALUE OF COAL AS RELATED TO ITS CHEMICAL COMPOSITION AND HEATING VALUE.

Figure 94 is a graphical summary of the results of all the steaming tests made at the fuel-testing plant at St. Louis, Mo. The figure shows how the chemical composition and the heating value of coal affect the economic results in steam production. The abscissas of the plat are the heat values of the coals as fired. The ordinates are values giving the approximate composition of coal and the two most important items of the results of the steaming tests, the capacity and the evaporation together with the efficiency.

When studying this figure careful note should be made of the scale to be used with each curve. The ordinates giving the percentages of ash, moisture, and the volatile matter in coal read from the top down; that is, when the curves drop these percentages increase. Attention is also called to the fact that the basis of these percentages is coal free from ash and moisture; that is, the percentage of moisture and of ash is that amount which would be present if the moisture and ash increased in the same ratio as actual combustible is increased to 100 per cent. The ordinates giving the capacity of boiler developed during each test and the evaporation, read from the bottom up; that is, when these two curves drop the capacity or the evaporation drops also.

Each of the plain points (○ or ●) on the chart represents a single test. The points with the crosses (⊕ or ⊕) through them represent the arithmetic averages of the surrounding groups of single tests.



99133°—11. (To face page 368.)

These average points are connected with broken lines to show the general tendency of the variation.

Through the group of evaporation points are drawn four lines of constant over-all efficiency of the steam-generating apparatus; that is, all tests falling on the same line were run with the same over-all efficiency. The top curve, or rather the top group of points, gives the capacity of the boiler that has been developed during each test. The average of this group runs between 90 and 100 per cent of the capacity as rated by the builders, and is nearly constant for all heat values of the coals. The fact signifies that by proper manipulation of the fires it is possible to obtain the rated capacity of the boiler with almost any coal, no matter what its heat value may be.

The second and the third group of points show that as the heat value of 1 pound of coal as fired decreases from 14,600 to 10,200 B. t. u., the ash and moisture increase from about 5 to 20 per cent. Undoubtedly this increase in moisture and ash is the direct cause of the low heat value of the coals at the right of the plat. The lowest curve (marked "volatile matter") shows that for the above decrease in the heat value of the coals the volatile matter increased from about 30 to 45 per cent, indicating that in general the coals used in the tests shown at the right of the plat are of lower grade than those at the left of the plat.

The second group of points from the bottom of the chart (marked "evaporation") gives the evaporation per pound of coal as fired. It is the most interesting group of points in the figure. The significant feature of this group is that the average drops very nearly in proportion to the heat value of the coal. It is worthy of note that the over-all efficiency drops only about 4 per cent when the heat value of the coal drops from 14,600 to 10,200 B.t.u. This drop in efficiency is not due to the low heat value of the coal, but to the large percentages of ash, moisture, and volatile matter in the coal as fired.

It has been stated in the discussion of the effects of ash on the economy in steam production, that a large percentage of ash reduces the efficiency by causing a large local air supply and at the same time may be also the cause of incomplete combustion. In the section on the effects of the moisture on economy, it has been shown that high moisture increases incomplete combustion and on account of the high latent and specific heats of water causes large chimney losses, thereby reducing the efficiency. High-volatile coals are always difficult to burn on account of the heavy hydrocarbon gases and tar vapors which are distilled from the fuel bed and must be burned in the combustion space of the furnace. Consequently when coals distilling larger quantities of these heavy gases and tar vapors are burned the combustion is not as complete as when their quantity is small. Therefore, one is justified in stating that the high volatile

matter of the coals used in the tests shown at the right of the plat is responsible for a part of the 4 per cent drop in the over-all efficiency.

Inasmuch as the evaporation per pound of moist coal in any steam-generating apparatus is nearly proportional to the heat value of the coal, it is plain that wherever possible coal should be bought on the B. t. u. basis. Moisture and ash-free coal coming from the same coal bed does not vary appreciably in heat value. Therefore after the heat value of a coal has been once determined with a calorimeter, the heat value of other lots of coal from the same bed may be closely computed from the moisture and ash determinations which any intelligent boiler-room operator can make. Inasmuch as large percentages of moisture, ash, and volatile matter in the coal increase the chimney losses and are the causes of less complete combustion a proper correction ranging from 1 to about 5 per cent should be made on the heat value of the coals.

The preceding deductions are drawn from the results of tests made in a hand-fired furnace under a Heine boiler, and are strictly applicable to that type of furnaces. However, the authors are confident that the same deductions hold true to a large measure with all mechanical methods of stoking coals.

PUBLICATIONS ON FUEL TESTING.

The following publications, except those to which a price is affixed, may be obtained without cost by applying to the Director, Bureau of Mines, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

PUBLICATIONS OF THE BUREAU OF MINES.

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp. 4 pls.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. F. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp.

BULLETIN 6. Coals available for the manufacture of illuminating gas, by A. H. White and Perry Barker. 1911. 77 pp., 4 pls.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 57 pp., 1 pl.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp.

BULLETIN 9. Recent development of the producer-gas power plant in the United States, by R. H. Fernald. 82 pp., 2 pls. Reprint of United States Geological Survey Bulletin 416.

BULLETIN 11. The purchase of coal by the Government under specifications, by George S. Pope. 80 pp. Reprint of United States Geological Survey Bulletin 428.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp.

BULLETIN 14. Briquetting tests of lignite at Pittsburgh, Pa., 1908–9; with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 64 pp., 11 pls.

BULLETIN 16. The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl.

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs, with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp., 2 pls.

BULLETIN 21. The significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 62 pp. Reprint of United States Geological Survey Bulletin 367.

TECHNICAL PAPER 1. The sampling of coal in the mine, by J. A. Holmes. 1911. 18 pp.

TECHNICAL PAPER 2. The escape of gas from coal, by H. C. Porter and F. K. Ovitz. 1911. 14 pp.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil by the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Transferred to the Bureau of Mines.]

PROFESSIONAL PAPER 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. $1.50.

BULLETIN 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

BULLETIN 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

BULLETIN 323. Experimental work conducted in the laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp.

BULLETIN 325. A study of four hundred steaming tests made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp. 20 cents.

BULLETIN 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes, in charge. 1908. 299 pp. 25 cents.

BULLETIN 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 10 cents.

BULLETIN 343. Binders for coal briquets, by J. E. Mills. 1908. 56 pp.

BULLETIN 362. Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

BULLETIN 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

BULLETIN 366. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 1908. 45 pp., 3 pls.

BULLETIN 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls. 10 cents.

BULLETIN 382. The effect of oxygen in coal, by David White. 1909. 76 pp., 3 pls.

BULLETIN 385. Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907-8, by C. L. Wright. 1909. 41 pp., 9 pls.

BULLETIN 392. Commercial deductions from comparisons of gasoline and alcohol tests on internal-combustion engines, by R. M. Strong. 1909. 33 pp.

BULLETIN 393. Incidental problems in gas-producer tests, by R. H. Fernald. C. D. Smith, J. K. Clement, and H. A. Grine. 1909. 29 pp.

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Bulletin 24

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

JOSEPH A. HOLMES, DIRECTOR

BINDERS FOR COAL BRIQUETS

INVESTIGATIONS MADE AT THE FUEL-TESTING PLANT ST. LOUIS, MO.

BY

JAMES E. MILLS

[Reprint of United States Geological Survey Bulletin 343]

WASHINGTON

GOVERNMENT PRINTING OFFICE

1911

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ILLUSTRATION.

BINDERS FOR COAL BRIQUETS:

INVESTIGATIONS MADE AT THE FUEL-TESTING PLANT, ST. LOUIS, MO.[a]

By JAMES E. MILLS.

INTRODUCTION.

THE COMMERCIAL PROBLEM.

Coal, in the process of mining, transportation, and handling and on exposure to the weather, is subject to more or less disintegration. This disintegrated coal is usually called "slack" and amounts often to a considerable percentage of the lump coal produced in the mines. If this slack coal is wasted the loss so occasioned ranges from 5 to 50 per cent, or even more, of the total coal mined. It is therefore clear that the utilization of this waste slack coal becomes a serious economic consideration.

When the coal is suitable for the production of coke, the utilization of the slack presents no difficulty, as it is in demand for that purpose. If the coal does not produce good coke, but cakes rather readily, the slack can be used for boiler purposes, as it fuses together more or less quickly, and burns on the furnace grate without great loss. Coal that cakes less readily can be burned on grates of special construction. When so used it is more troublesome to handle, and the waste is greater than when lump coal is used. Consequently the price of much of the slack coal for fuel purposes ranges considerably lower than that of the lump coal from the same mine.

The full value of this slack coal as fuel can be realized by first forming the coal into a coherent mass or briquet, such briquets, when of good quality, being equal to or of greater value than the original

[a] The writer undertook the work herein reported, in 1905, at the fuel-testing plant of the United States Geological Survey, under the direction of Dr. Joseph Hyde Pratt, of the University of North Carolina, to whom he is greatly indebted for advice and suggestions, given not alone at the beginning but throughout the progress of the work. Acknowledgment is also due for suggestions given by Mr. A. A. Steel, of the University of Arkansas, and for the assistance of many individuals and corporations who have answered inquiries and furnished samples as desired. In compiling this report and in laboratory work free use has been made of all available information thus acquired.

lump coal from which the slack was derived. The object of the investigations herein reported was to determine as far as possible to what extent the manufacture of briquets from slack coal may succeed commercially under the conditions existing in the United States.

The problem of briquetting is not always that of how to make the best possible briquet, for the slack at hand may be of inferior quality and the best possible binding material may be too expensive for the conditions prevailing in that particular locality. The problem is always to produce at a profit a briquet of satisfactory grade for the use intended. This problem will be made clearer by a brief summary of the available binders, followed by a preliminary discussion of the characteristics of a good briquet.

THE KIND OF BINDER.

Definite answer to the question "What is the best binder to use in making briquets?" depends, as repeatedly emphasized in this paper, on the locality, on the character of the coal, and on the purpose for which the briquets are intended. For purposes of a brief comparison consideration is given to the binders available for a coal which is fairly easy to briquet and which cakes rather readily. A few coals will briquet with somewhat less and others require greater percentages of binder, but an endeavor has been made in the following summary to strike a reasonable average.

The experiments herein reported show that, in general, for plants situated where it can be obtained, the cheapest binder will prove to be the heavy residuum from petroleum, often known to the trade as asphalt. Four per cent of this binder being sufficient, its cost ranges from 45 to 60 cents per ton of briquets produced. This binder is particularly available in California, Texas, and adjacent territory.

Second in order of importance comes water-gas tar pitch. Five to six per cent usually proving sufficient, the cost of this binder ranges from 50 to 60 cents per ton of briquets produced. As water-gas pitch is also derived from petroleum, it will be available more particularly in oil-producing regions.

Third in order of importance is coal-tar pitch. Being derived from coal, this binder is very widely available. From 6.5 to 8 per cent will usually be required, and the cost ranges from 65 to 90 cents per ton of briquets produced.

Of local importance, where the price permits, are natural asphalts and tars derived from wood distillation. The price of each of these binders varies greatly with the locality, but there are doubtless places where they could compete with the binders above mentioned. Wax tailings could be used with an easily caking coal.

Pitch made from producer-gas tar is not yet on the market, but it will produce excellent briquets, with a lower percentage of binder

than other coal-tar pitches. It will doubtless be available in the future.

Briquets excellent in all respects except that they are not waterproof can be made by using 1 per cent of starch as a binder, the cost of which is 20 cents per ton of briquets produced. Extra care is necessary in drying and handling these briquets, and this adds to their cost.

The waste sulphite liquor from paper mills also produces excellent briquets except that they are not waterproof. At present it is a troublesome waste product dissolved in much water. Its utilization for this purpose will bear further investigation.

Of inorganic binders, magnesia might be utilized, as its probable cost would not exceed 22 to 30 cents per ton of briquets produced. Other inorganic binders, while available as regards price, would not make first-class briquets.

The briquetting of lignite coal offers a peculiarly difficult problem. If the lignite cakes in the fire, asphaltic residues from petroleum or water-gas tar pitch may be used as binder, larger percentages being required than for ordinary coals. The most promising binders for lignites that do not cake are starch, sulphite liquor, and magnesia. Lignites may be briquetted without binder if they are to be burned on grates specially constructed to overcome the tendency to fall to pieces in the fire.

Attention is called to the suggested method of deciding as to the value of coal-tar pitch for briquetting purposes. The method is likewise applicable to asphalts and petroleum residues generally: (1) The pitch or tar is distilled and all oils coming off below 270° C. are rejected as being of no value; (2) the flowing point of the portion to be used in briquetting is determined (this should generally not be less than 70° C.); (3) the pitch is extracted with carbon disulphide. The smaller the amount of residual carbon the more satisfactory is the pitch. The less readily the coal cakes the higher must be the flowing point of the pitch. If a pitch cracker is used, the pitch to work successfully on a hot summer's day must have a flowing point above 120° C. In the winter pitch with a flowing point of 100° C. may be used. All softer pitches and asphalts have to be melted and mixed in liquid form with the coal.

A pitch with a very high softening point, above 150° C., should be either thinned or superheated in the mixer. The efficient use of a binder depends very largely on the proper regulation of the conditions in the mixer. The presence of low-volatile compounds in the pitch to be used as a binder increases the smoke in burning; and also increases the tendency of the briquet to soften and crack open in advance of combustion, owing to the volatilization and escape of these compounds.

The main problem in briquetting is to find a suitable binding material at sufficiently low cost. When the difference in price between the slack coal and the first-class lump coal is $1, the cost of briquetting should not exceed this amount. Of this the binder must cost less than 60 cents per ton, as the cost of manufacture averages about 40 cents. To leave out of consideration the possible advantages in the use of briquetted coal over run-of-mine coal, due to the greater efficiency and smokelessness of briquets, it will probably not be necessary to pay any attention to binding materials costing $1.25 or more per ton of briquets produced.

CHARACTERISTICS OF GOOD BRIQUETS.

COHERENCE.

The briquet should be sufficiently coherent. In France briquets are tested for coherence as follows:[a]

One hundred and ten pounds of briquets are divided into 100 pieces of 1.1 pounds each, which are placed in a cylinder 36.22 inches in diameter and 39.57 inches in length. This cylinder is divided into three compartments by diametrical partitions and revolves at a speed of 25 revolutions per minute. After being charged, it is revolved for two minutes, and the contents are thereupon sifted upon a screen perforated with holes 1.12 inches square. The proportion which does not pass through this screen indicates the degree of cohesive force, which, in the case of the French Admiralty tests, should reach 52 per cent, or if the fuel be intended for torpedo boat use, 58 per cent.

Briquets of any desired degree of coherence may be made by varying the amount of binding material used in the briquet and by varying the pressure. An increase of either the binder or the pressure, of course, represents an added cost in manufacture. Experiments made by M. Wèry, of Paris,[b] with a Biétrix machine may be taken as illustrative:

Effect on coherence of varying pressure and amount of binder.

Pressure in kilograms per square centimeter.	Pressure in pounds per square inch.	Per cent of pitch used.	Per cent of cohesion obtained.
130	1,844	6	25
190	2,695	6	46
270	3,831	6	61
130	1,844	7	52
190	2,695	7	70
250	3,547	7	74

Ordinarily briquets may be considered sufficiently coherent when the loss occasioned by dust and breakage involved in their use does not exceed 5 per cent. Both manufacturers and consumers should recognize the desirability of adapting the briquet to the use intended.

[a] Briquets as fuel: Special Consular Report, vol. 26, p. 54.

[b] Idem., p. 50.

HARDNESS AND TOUGHNESS.

The briquet should be sufficiently hard; but if too hard it is likewise brittle, and therefore less coherent when subjected to rough handling. It is usually advantageous, therefore, to make the briquet of the minimum hardness that will suffice for the purpose in view. A briquet can be made harder by using a binder with a higher softening (melting) point. Consequently, if pitch is used, the most brittle pitch makes the hardest briquet. Moreover, a larger percentage of the more brittle pitch is usually required.

The requirement of the French Admiralty is that the briquet should not soften at 60° C. (140° F.). Ordinarily it is sufficient that the briquet shall not soften on the hottest day, and shall behave satisfactorily on burning.

DENSITY.

It is sometimes specified that the briquet should have a density of not less than 1.19. Perhaps a better standard would require the briquet to about equal in density the lump coal from which the slack was derived, thus ranging from 1.1 to 1.4. The density is increased by pressure.

SIZE AND SHAPE.

The convenience of a briquet for a given purpose, and hence the extent of its use, will depend largely on the size and shape. Attention is therefore called to the following points:

Heavy rectangular blocks allow a large output for the investment and are consequently cheaper to manufacture. They are convenient for storage. The French naval estimates show that 10 per cent more in weight of briquets can be stored in a given space than of lump coal, and the British Admiralty reports show a gain of as high as 20 per cent. Large rectangular briquets have the disadvantage of large smooth surfaces and are usually broken up when fed into furnaces, as this appears to promote combustion. To facilitate the breaking they are pressed with grooves or perforations. This gives better air circulation but decreases the output and the possibility of storage by just so much.

Prismatic shapes with rounded edges are most popular abroad. Either these or ovoid shapes of less than 2 pounds weight are preferred for domestic use. The rounded edges cause much less dust and breakage on handling and insure good air circulation and thorough combustion, but are wasteful in space and make the briquet somewhat harder to ignite.

The output of hollow, cylindrical, polygonal, and ball-shaped briquets abroad is small, the other shapes having proved more generally preferable.

WEATHERING.

The briquet should stand long exposure to the weather with but little deterioration. A dense briquet will stand the weather better than a porous one. In the process of manufacture briquets are liable to crack if they lack the proper proportion of binder, or if the binder and coal particles have been improperly mixed, or if the briquets are pressed too wet, or are insufficiently pressed. If the coal is finely ground, the briquet assumes a more dense and polished surface and is then more resistant to the weather. Cracks, however produced, allow the entrance of moisture and cause a rapid deterioration of the briquet on exposure to the weather. Lignite briquets, owing probably to the tendency of the lignite to absorb water and also to the more porous structure of the briquet, do not stand long exposure to the weather as successfully as other briquets.

The binder used must be insoluble in water. The great obstacle to the successful use of starch, molasses, and sulphite-liquor residues as binders is their solubility, the cost of rendering the briquet waterproof being usually prohibitive. It is deserving of serious consideration whether or not in certain dry portions of the West, where fuel is scarce, the waterproofing of the briquet could not be dispensed with altogether during the dry season, and to a considerable extent during the rainy season by keeping the briquets under cover.

With pitches, tars, etc., a slightly increased percentage of binder is necessary in briquets that are to stand long exposure to the weather. Further details are given under the discussion of the various binders.

ABSORPTION.

The briquet should not absorb more than about 3 per cent of moisture. The amount of moisture absorbed is increased when either the slack itself or the briquet is porous, or when the binder used has a tendency to attract moisture.

BURNING QUALITIES.

Readiness of ignition.—The ease with which a briquet will ignite depends largely on the slack used, but can be regulated to some extent. Large briquets ignite less readily than small ones. Sharp edges are an aid to ignition, though this advantage is not so great as to overcome the general preference for the prismatic and egg-shaped briquets. Briquets made from fine slack ignite less readily than those from coarser slack. A dense briquet is also more difficult to ignite. The use of an inorganic substance, such as clay or magnesia, as a binder, or as a constituent of the binder, tends to make the briquet ignite less readily. Increase of inorganic material—that is, ash—in the slack coal used produces the same result.

Kind of flame.—The briquet should burn with a clear, intense flame, and without odor or smoke. The burning of the briquet and the flame produced, as well as the smoke given off, will depend largely on the quality of the slack coal used and on the completeness of the combustion. The completeness of combustion can be regulated to some extent in the manufacture of briquets by making them of a shape to insure a good air circulation and by the choice of a suitable binder. So far as the choice of a binder for this purpose is concerned, the principle involved may be summed up in the statement that the smoke does not depend on the total amount of volatile matter in the briquet, but only on that part of the volatile matter which escapes before it is heated to the kindling temperature. In other words, the binder should not volatilize before the temperature is sufficiently high to insure complete combustion of the gases formed. In general terms, therefore, a binder adds smoke in proportion to the amount of low-boiling constituents (oils, etc.) that it contains.

Inorganic binders, of course, produce no smoke. Such organic binders as starch, molasses, or sulphite-liquor residues likewise do not volatilize until decomposed, and hence do not smoke, or smoke but little. Pitches, tars, and petroleum residues, when used as binders, volatilize, and will cause smoke and possibly odor if the gases formed are not completely burned. But it is quite possible to regulate the conditions, even when using these binders, in such a way that the briquets will produce less smoke than the lump coal from the screenings of which the briquet is made. This is due to the regular shape of the briquet, which allows a better-regulated air supply, enabling more complete combustion to take place. This reduction of the smoke nuisance is one of the advantages to be derived from the use of briquets.

Retention of shape.—The quality of retaining its shape in the fire is very important and depends on the properties of both the coal and the binder used in making the briquet. This point is discussed more fully in connection with the various coals and binders examined. The principle involved is very simple. The binder must hold the coal particles together until they are sufficiently softened to cohere. The temperature at which different coals soften or cake together varies greatly. Some bituminous coals cake readily at a low temperature, others less so. Semianthracite coals follow next in order, and then anthracite coals, some of the very hard anthracite coals with only a small amount of volatile matter showing little tendency to cake. Lignites as a class do not cake readily. Some, however, as those from Oklahoma or New Mexico, will cake sufficiently at a rather high temperature to hold themselves together. Others, as some California, Texas, or North Dakota lignites, show practically no tendency to soften or cake at any temperature. With such lig-

nites it is extremely difficult to make a briquet that will retain its shape in the fire. Briquets satisfactory for domestic use, when properly managed, can be made from such lignites. These briquets might be used in a variety of manufacturing operations if a grate suitably adapted to the fire box is provided. For use in a locomotive they would be less suitable.

With a readily caking coal, a binder that volatilizes (boils) at a comparatively low temperature may be used. With coals that cake at higher temperatures a less volatile binder must be used to obtain a satisfactory result in the fire. With a lignite that does not cake, the only binder that will enable the briquet to retain its shape until completely consumed is an inorganic binder which does not volatilize at all—unless, indeed, sufficient binder is added to practically coke the briquet. With such lignites, organic binders that do not volatilize, such as starch, molasses (in the form of waste residues from the sugar factories), sulphite-liquor residues from the paper mills, etc., give results that are fairly satisfactory, the briquet retaining its shape until the binder is itself decomposed. As the inorganic binders add ash and the other nonvolatile binders mentioned are not waterproof, it would seem generally better, where commercially possible, to mix a coal that will not cake of itself with a sufficient quantity of caking coal. Then when a suitable binder is used the briquet will retain its coherence in the fire by the softening of the caking coal used. The relation between the caking of a coal and its constitution is not well understood.

Percentage of ash.—The amount of ash left when the briquet is burned is the sum of that contained in the slack and in the binder used. Organic binders, as a rule, contain a smaller percentage of ash than the slack coal, and therefore slightly decrease the total percentage of ash in the briquet. When inorganic binders are used the ash thus added is a decided disadvantage.

In some foreign countries only 6 per cent of ash is permitted under many of the contracts for briquets. When the ash content of the slack exceeds 6 per cent it is therefore quite common abroad to wash the slack coal before briquetting. This saves freight on an incombustible material, saves binder, and gives in every way a better and more concentrated fuel. In this country, where good coal is so much cheaper than abroad, it will probably not usually prove feasible to wash the slack coal.

EVAPORATION RESULTS.

Theoretically the heating value of a briquet is the sum of the heating values of the coal and of the binder; and it can not possibly exceed this amount. Organic binders usually equal or exceed in heating value, weight for weight, the slack coal used. Usually,

therefore, they increase the total heat in a given weight of fuel, but owing to the small percentage of binder added, this increase is relatively slight. But the briquets have the advantage over the coal in that their burning is accompanied with less waste and they permit a better-regulated and more complete combustion to take place. In this way the heating value actually obtained from the fuel, weight for weight (and this, of course, is the important consideration), may be materially increased by the manufacture of the fuel into briquets. This increased heating value of the briquets over that of the slack used thus becomes a matter of practical importance.

The evaporation results should at least equal those of the best lump coal from the screenings and dust of which the briquet was made.

CONDITIONS GOVERNING THE USE OF BINDERS.

MAXIMUM COST ALLOWABLE FOR BINDER.

The output of a briquet plant depends to a very great extent on the size of the briquets manufactured. The cost of labor depends greatly on the size and arrangement of the plant and on the wages paid, which will vary considerably in different localities. The price of slack coal and of the different binders is even more dependent on the locality. An approximate idea of the total cost of manufacture, exclusive of the cost of the slack coal and the binder used, is here presented, in order to consider intelligently estimates which may be made of the maximum allowable cost of the binder, it being obviously useless to investigate a binder that could never be commercially used on account of its cost. E. Loze[a] estimates the cost for manufacture in France at 33 to 40 cents per ton. Schorr[b] states that the cost in France is 24 to 34 cents per ton; in Germany, 22 cents to 24 cents; and in England, 24 cents. Estimates of the cost in the eastern and western parts of the United States are as follows:

Estimated cost per ton of manufacture of briquets in the United States (exclusive of binder and of coal briquetted).

	Western States.	Eastern States.
Labor, inclusive of stacking	$0.16	$0.20
Oil and grease	.006	.01
Sundry stores	.01	.01
Steam (fuel)	.04	.17
Depreciation	.05	.10
	.266	.49

Considering 30 to 50 cents per ton, therefore, as being approximately the cost of manufacture, it appears that when the difference in price

[a] Eng. and Min. Jour., vol. 76, 1903, pp. 277, 431.
[b] Trans. Am. Inst. Min. Eng., vol. 35, 1904, p. 100.

between the slack coal and the first-class lump coal is $1, the binder must cost less than 50 to 70 cents per ton. Good briquets would probably find in many places a market at a price slightly advanced over that of the corresponding lump coal from the screenings of which the slack was derived. Yet it is evident that the main problem in briquetting is to find a suitable binding material at a cost sufficiently low. A binding material costing as much as $1 per ton of briquets produced could be used profitably in but few places in the United States. Even allowing for future possible greater variation in price between the coal and the slack it is not necessary to pay attention to any binding material costing above $1.25 per ton of briquets produced.

QUALITIES DESIRED IN BINDERS.

It is needless to say that a desirable binder should make a good briquet and should make it cheaply. The characteristics of a good briquet have already been pointed out. It will not, perhaps, be too great a repetition to summarize here, in the approximate order of their importance, the desirable qualities of a binder, as follows:

1. It must be sufficiently cheap to make the manufacture of briquets profitable.
2. It must bind strongly, producing a briquet sufficiently hard, but not too brittle.
3. It must hold the briquet together satisfactorily in the fire.
4. It must produce a briquet sufficiently waterproof to stand the conditions of use.
5. It should not cause smoke or foul smelling or corrosive gases, or foul the flues.
6. It should not increase the percentage of ash or clinker.
7. It should increase, or certainly not diminish, the heat units obtainable from a given weight of fuel.

EFFECT OF QUALITY OF BINDER ON THE BRIQUET.

SCOPE OF THE INVESTIGATIONS.

The behavior of a large number of different coals with a few binders and of a few coals with a large number of different binders has been very carefully studied. Tests were made with each coal and with each binder until the percentage of binder required to produce a satisfactory briquet with that coal was determined. The behavior of the briquets in the fire and, when necessary, in water was noted. The binders used were examined as to their chemical or physical properties and such modification of the binder was made as seemed likely to produce more efficient results.

The conclusions that follow are submitted as the net result of the studies thus outlined.

PHYSICAL RELATION OF COAL AND BINDER.

The relation between the coal and the binder is purely physical. Chemical action, if coming into play at all, is so slight in amount as to be wholly negligible. Moreover, the properties of the binder are not greatly changed by the mutual solubility, or surface action, of coal and binder at the surface of the coal.

The above statements are shown to be true by the fact that if the coals are arranged in a series according to the percentage of one binder required, they will retain that same order when other binders are used, even when these binders are of the most diverse nature. The experiments of Constam and Rougeot[a] show that the soluble portion of the binders (various pitches) could be extracted from the briquets practically quantitatively with carbon disulphide, and that this reagent extracted at the most only 0.7 per cent from the coal.

The properties of the briquet are the properties of the coal plus the properties of the binder, and the combination of the two in briquetting does not materially change the properties of either. Not only is this observation true of briquets at ordinary temperatures, but it is also confirmed by their behavior in the fire. The decomposition of the binder caused by the heat may alter its character to some extent, but never, so far as the writer has observed, sufficiently to mask its original character. The action of the briquet in air and in water also confirms the truth of the above observation.

QUALITIES OF BINDER IMPARTED TO BRIQUET.

If the binder is brittle the briquet will be relatively brittle at the same temperature. Thus rosin, hard pitches, asphalts, cements, etc., make briquets that are hard, but they break easily from a sharp blow or fall. Liquids such as coal tar, creosote, asphalt tar, etc., make briquets that do not break easily from a fall, but they yield so readily to pressure as to be useless. Comparable percentages of binder being used, the toughest briquet—that is to say, the briquet that will stand the most rough usage—is made with a binder that at ordinary temperature twists easily and pulls into threads, that will cut with a knife rather than break, and that flows very slowly, taking some time to assume the shape of the container. Such a binder is sufficiently elastic not to be brittle and is sufficiently stiff not to yield to climatic changes of temperature. Binders that have been examined fulfilling this condition are pine-wood tar (12),[b] water-gas tar pitch (39), wax tailings (40), and residuums from petroleum, often designated as asphalts (37 A, 37 B, and 37 C). Satisfactory briquets are made with 3 to 5 per cent of the above binders. If the coal does

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[a] Zeitschr. f. angew. Chemie, vol. 17, No. 26, p. 1.

[b] Numbers refer to list on p. 22.

not cake readily a binder with a higher melting point would be required to make the briquet retain its shape in the fire.

BEHAVIOR WHEN HEATED.

The binder will soften when in the briquet as soon as it is heated to the temperature at which it softens when outside of the briquet. Such softening will not be so apparent, however, for the binder exists in the briquet as a very thin coating over the grains, and if it melts to a thick, sticky liquid, rather than to a limpid one, its cohesive power in the state of a liquid is still very great. But it must be borne in mind that all briquets have a temperature of maximum weakness in the fire. This temperature lies in the interval between the melting or destruction of the binder and the softening of the coal as it commences to cake. If the coal softens at a high temperature the binder must melt at a relatively high temperature to give satisfactory results in the fire. If the coal does not cake at all, then the binder must not melt at all, or be destroyed by the heat, if a perfectly coherent briquet at all temperatures is desired. Only inorganic binders could fulfill this condition, and their use is objectionable. Organic binders that do not melt, such as starch, etc., give the best results in the fire with a noncaking coal, but are not waterproof.

In a furnace the briquet does not become thoroughly heated throughout at the same time, and as the binder near the surface of the briquet melts and passes out as a gas, the binder in the next interior layer of the briquet to some extent takes its place, and so on. In this way the briquet is held together until the coal at its surface softens and cakes. When this happens the briquet commences to regain its strength and with many coals soon becomes stronger than when placed in the fire.

The binder will volatilize out of the briquet and appear as a gas as soon as it reaches the temperature at which it boils when outside of the briquet and in the pure condition. If this happens much below the kindling temperature of the gas some smoke and odor will be caused, and the smoke and odor may to a large extent be taken as proportional to the low-boiling oils in the binder—at least so far as the smoke is caused by the binder and not by the coal.

SOLUBILITY.

If the binder used is to any extent soluble in water the briquet will not withstand exposure to wet weather. The binder will go into solution as surely, though more slowly, in the briquet, as when it exists in the pure condition outside of the briquet, unless the briquet is in some way rendered waterproof.

QUANTITY OF BINDER NECESSARY.

SURFACE TO BE COATED.

The fact that the binder exists unchanged in the briquet, its office being solely to coat the grains, fill up void spaces between the grains, and by its adhesive and cohesive properties hold the briquet together, points to the following conclusions.

The amount of binder required will depend on the amount of surface to be coated, and the amount of surface will depend on the size of the grains, on their density (that is, the density of the dry coal), and on the capillary pores in the coal. The theoretical relation between the amount of surface to be coated, the size of the grains, and the density of the coal can be easily computed.

Let w = weight of coal taken. Suppose the grains of coal to be spheres, and let r = radius of the sphere. Let d = density of the coal. Then the volume of the sphere is $\frac{4}{3}\pi r^3$. The weight of the sphere is $\frac{4}{3}\pi r^3 d$. The number of grains of coal in the weight of coal taken is $\frac{w}{\frac{4}{3}\pi r^3 d.}$ The surface of each grain is $4\pi r^2$, and the total surface to be coated is $\frac{3w}{rd.}$

That is, the amount of surface to be coated varies inversely with the density of the coal and inversely with the diameter of the grains. The same law can be shown to apply whatever the shape of the grains.

The practical bearing of this relation is important. Thus, suppose a coal of density 1.4 requires 6 per cent of pitch to make a satisfactory briquet. Then a coal of density 1.1, other things being the same, would require 7.63 per cent of pitch, or 1.63 per cent more pitch than is required by the denser coal. This is one reason why lignite coal with a low specific gravity requires more binder than the average coal.

The variation in the size of the grains of coal has an even greater influence on the amount of binder required. The table below shows the relative amount of surface to be coated in coal slack of varying degrees of fineness:

Relation between size of grains and amount of surface.

Number of meshes to inch.	Diameter of wire (inch).	Size of mesh (millimeters).	Relative amount of surface.	Number of meshes to inch.	Diameter of wire (inch).	Size of mesh (millimeters).	Relative amount of surface.
1	0.131	25.400	1	80	0.00575	0.230	110
2	.103	12.700	2	100	.00450	.170	150
4	.079	5.350	4	200	.00235	.085	300
10	.027	2.000	12.7	....	....	.005	5,080
20	.01650	1.000	25.4	....	....	.0025	10,160
30	.01375	.670	37.9	....	....	.00075	33,900
40	.01025	.500	50.8	....	....	.00025	101,600
50	.00900	.310	81.9				

It will thus be seen that coal slack which will just pass a 20-mesh sieve has 6.35 times as much surface to be coated as the same weight of slack crushed so as to pass a screen of ¼-inch mesh, and that coal passing a 200-mesh sieve has 75 times the surface of coal just passing the ¼-inch mesh. The very finest dust, having a diameter of 0.00025 millimeter, has 25,400 times the surface of coal just passing the ¼-inch mesh.

This consideration is not purely theoretical. The remark of Wagner,[a] that it took 20 per cent of pitch to briquet certain fine coal dust, is illustrative of its practical bearing. The degree of fineness of the slack coal used is one of the main factors in determining the percentage of binder necessary to produce a satisfactory briquet.

To illustrate this point, mention is here made of a fact shown later, that all coal-tar pitches contain a certain amount of carbon (soot), which, being in a very finely divided condition, is not only inert so far as binding the coal together is concerned, but itself requires a binder. Owing to the dustlike condition of this carbon its effect on the binding power of the pitch for the coal is most marked. Thus, although a coal-tar pitch (28 G) that contained 14 per cent of this inert, finely divided carbon made a satisfactory briquet with Illinois No. 4 coal when 6 per cent of the pitch was used, yet another coal-tar pitch (28 I) containing 37 per cent of the inert carbon failed to make a satisfactory briquet with the same coal when 14 per cent of the pitch was used. On the market the pitches sell at approximately the same price. The serious mistake made in crushing coal slack too fine is apparent.

Fine crushing of the coal slack gives the briquet a smoother surface that is more resistant to the weather; but this increase in the quality of the briquet is usually obtained at too great a cost, owing to the additional binder required, as explained above. Fine crushing also makes the briquet somewhat harder to ignite.

Capillary pores increase the amount of surface to be coated and the amount of void space to be filled, and this is probably another reason why lignites require more binder than hard coals.

It is interesting, in this connection, to note that with all binders the coherence in the briquets at first increases but slowly with increase in the proportion of binder. Then suddenly the coherence increases very rapidly and the briquets become strong. Then when an excess of binder is added the increase in strength is again only slight. The curve takes the form indicated in the accompanying diagram (fig. 1). The explanation, of course, lies in the fact that at first there is not enough binder to coat all the grains of coal and there can be little coherence. When sufficient binder has been added to coat the grains, the strength increases rapidly. After the grains have been well

[a] Cassier's Magazine, vol. 11, 1896, p. 23.

coated there is little further gain in strength with the use of additional binder.

PERCENTAGE OF VOIDS.

The amount of binder will depend on the amount of void space to be filled. There should always be enough of the finer coal and coal dust present to fill the spaces between the larger grains, or binder will be required to fill these spaces. Thus Wagner also found that a very large amount of binder was required to bind coal slack of a uniform size, five-sixteenths to three-eighths inch in diameter. Clifford Richardson, in a recent book on "Modern asphalt pavements," gives a calculation by Dr. G. F. Becker, of the United States Geological

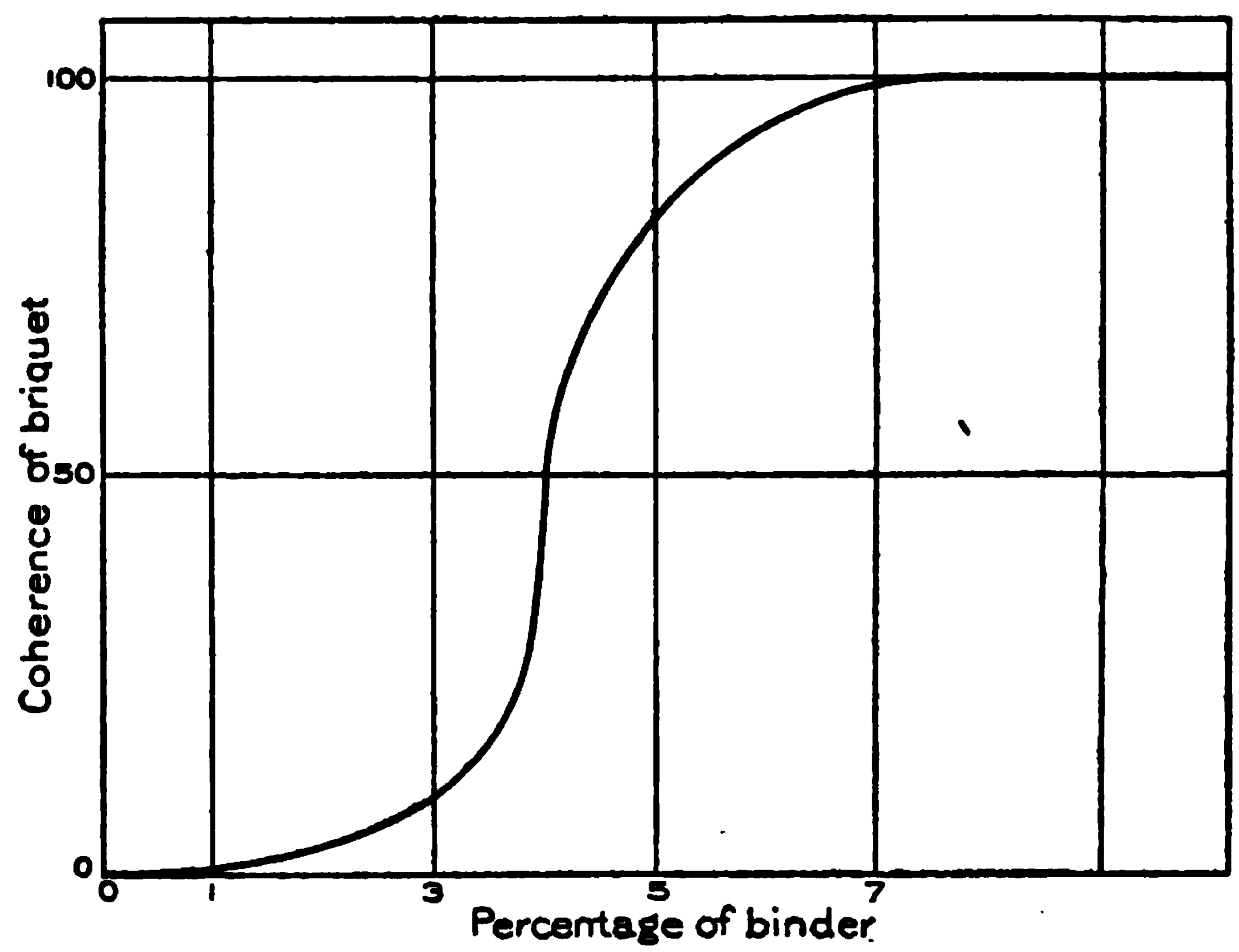

FIG. 1.—Curve showing relation between percentage of binder (water-gas tar pitch) and coherence of briquet. Other binders show similar curves, but with different percentages.

Survey, as to the amount of void space. This calculation is in outline as follows:

Consider four spheres in a plane so arranged that the lines joining their centers form a square, and four other spheres above them. A cube is formed by the lines joining the centers of the eight spheres. If r is the radius of a sphere, then the volume of the cube is $8\ r^3$ and the void space is $8\ r^3 - \frac{4}{3}\ \pi\ r^3$, and the percentage of void space is $\frac{8\ r^3 - \frac{4}{3}\ \pi\ r^3}{8\ r^3} = 1 - \frac{\pi}{6} = 0.4764$. If the spheres are placed obliquely, then the area of the parallelogram joining their centers is $2\ r^2\ \sqrt{3}$, and multiplying this by the height of a tetrahedron formed by the centers of four spheres when three are placed in contact in one plane

and the fourth is placed on them, we have for the volume of the prism $4\sqrt{2}\ r^3$. Then for the percentage of voids we will have

$$\frac{4\sqrt{2}\,r^3-\frac{4}{3}\pi r^3}{4\sqrt{2}\,r^3}=1-\frac{\pi}{3\sqrt{2}}=0.2595.$$

From these results it will be seen that the amount of void space between grains of uniform size is independent of the size of the grains. In practice, however, even shot will not pack quite so closely as the theory indicates, as is shown by the experiments of Richardson, who found that with shot the percentage of void space was about 32.[a]

With grains of sand of uniform size but of irregular shape Richardson found the void space to average 43.6 per cent. It may be said, therefore, that in briquetting coal, 56.4 per cent of the total weight of the slack should be in grains about one-fourth inch in diameter.

It is interesting to obtain some idea of the desirable fineness of the remaining coal particles. Without giving the calculation in detail we may say that theoretically the spheres fitting in the spaces between the larger spheres, and the yet smaller spheres fitting into the void places then left can be calculated. The calculation shows that if r represents the radius of the large sphere there would be for every large sphere one smaller sphere having a radius of .4142 r, two spheres having a radius .2247 r, five spheres having a radius .1763 r, and eight spheres having a radius .1543 r. The volume occupied by these smaller spheres will be 11.14 per cent of the total volume, and since the large spheres occupy 74.05 per cent of the total volume, we would have about 15 per cent of void space to be filled in by yet smaller spheres. With irregular grains the results would not follow the theoretical percentages; but in a general way it is apparent that although it is advantageous to have a large percentage of the grains coarse (say 60 per cent of ¼-inch diameter), yet a considerable amount (say 40 per cent passing a 20-mesh sieve) of the finer slack and dust must be present to fill the voids.

The coal used in briquetting being already for the most part fine slack, the best practical results will be obtained by not breaking any of the lumps that are larger than one-fourth inch in diameter more than is necessary to bring them to that diameter and by not crushing the finer coal at all.

THICKNESS OF COATING.

The amount of binder necessary will depend on the thickness of the coat of binder over the surface of the grains of coal. The thickness of the coat of binder required will vary both with the coal and the

[a] This is partly accounted for by the fact that the discussion of Doctor Becker does not consider the contact of the spheres with the walls of the container.—J. E. M.

binder, but principally with the binder. In general, it may be said that the binder should be dissolved or heated until it is in the condition of a thin liquid capable of wetting the grains, somewhat as water would. With the harder pitches or asphalts, and similar binders, superheated steam for the mixers is a matter of necessity for economical working, for otherwise the binder does not become sufficiently liquid to spread in a thin coat and is therefore wasted.

OTHER CONSIDERATIONS.

The amount of binder required will depend to a slight extent on that portion of the coal which, being soluble in carbon disulphide, may be regarded as "bitumen" and as having some binding power. Constam and Rougeot[a] never found the amount of carbon disulphide extract to exceed 0.7 per cent, and probably with most coals the amount is negligible.

If the coals are arranged in a series according to the percentage of one binder required they will retain that same order in the series when other binders are used. Furthermore, if the equivalent percentages of different binders are determined for one coal then these equivalent percentages can be used for all coals, slight modifications only being sometimes necessary. An advantageous arrangement would be to place coals as ordinates and binders as abscissas in a table, and then the percentages of any binder required with any coal could be read directly.

LABORATORY INVESTIGATIONS OF VARIOUS BINDERS.

METHODS AND SCOPE OF THE EXAMINATION.

DETERMINATION OF PERCENTAGE OF BINDER.

In order to determine in the laboratory the percentage of pitch necessary to briquet a given coal, 20 grams of coal, unless otherwise stated in the detailed report, was weighed out, mixed with the chosen percentage of binder, and placed in a Battersea crucible. A small amount of water was then added and the mixture heated, with sufficient stirring to mix the binder and coal thoroughly, until steam came off freely and only a small amount of water was left in the coal. The mixture while still hot was pressed in a small laboratory hand press, on which a pressure of 3,500 to 4,000 pounds per square inch was usually obtained. Each briquet made weighed about 5 grams, and thus four briquets were obtained as representing the test. The percentage of binder was varied in subsequent tests until the correct percentage to produce a satisfactory briquet was determined.

The percentage of binder was always calculated on the weight of the coal, consequently the percentage calculated on the weight of the

[a] Zeitschr. f. angew. Chemie, vol. 17, No. 26, p. 1.

briquet produced would be somewhat less. This is a matter of no consequence, however, as the method of grading the briquet was purely relative.

DETERMINATION OF COHERENCE.

The examination of the small briquets produced was somewhat crude—their coherence being determined by the way in which they crushed or broke. The briquets were graded by numbers as follows:

1. Very slight coherence.
2. Slight coherence.
3. Coherent, but not satisfactory.
4. Satisfactory.

4½. Excellent briquet; would stand rough handling.

5. A briquet stronger than necessary.

It was found somewhat difficult to compare extremely hard and brittle briquets with others not brittle but too soft. In all tests the intention was to produce a relative grading in which 4 would represent a satisfactory briquet for ordinary use. In actual work the coherence of the briquet could be varied to suit the demand of the customer, but in no case probably would such variation exceed the range represented by the numbers 3½ to 4½.

LIST OF MATERIALS STUDIED.

The materials used to bind the particles of coal together may be either organic or inorganic, and a very large number of substances have at various times been suggested and used for this purpose.

A list of the binders which have been examined is given below. An effort has been made to include in this list all binders which it was thought might be used commercially in the United States, as well as certain other substances which seemed fitted to throw light on the laws governing the action of the binder. Attempt was made to study such modifications and combinations of the different binders as it seemed might produce more efficient commercial results. For these latter modifications and combinations reference must be had to the detailed report.

INORGANIC BINDERS.

(1) Clay, (2) lime, (3) magnesia, (4) magnesia cement (magnesium oxide and magnesium chloride), (5) plaster of Paris, (6) Portland cement, (7) natural cement, (8) slag cement, (9) water glass.

ORGANIC BINDERS.

Wood products.—(10) Rosin, (11) pitch (rosin and tar), (12) pine-wood tar, (13) hard-wood tar, (14) Douglas fir tar, (15) wood pulp, (16) sulphite liquor (from paper mills).

Sugar-factory residues.—(17) Beet pulp, (18) lime cake, (19) beet-sugar molasses, (20) cane-sugar molasses.

Starch.—(21) Corn starch, (22) potato starch.

Slaughter-house refuse.

Tars and pitches from coal.—(23) Blast-furnace tar, (24) producer-gas tar, (25) illuminating-gas tar, (26) by-product coke-oven tar, (27) coal-tar creosote, (28) various grades of pitches from various tars.

Natural asphalts.—(30) Impsonite, (31) gilsonite, (32) maltha, (33) refined Trinidad, (34) refined Bermudez, (35) hard and refined asphalts (from impregnated sandstones, etc.).

Petroleum products.—(36) Crude oil, (37) residuum (asphalts, etc.), (38) water-gas tar, (39) water-gas tar pitch, (40) wax tailings, (41) acid sludge, (42) asphalt tar, (43) Pintsch gas tar, (44) Pittsburg flux.

INORGANIC BINDERS.

GENERAL STATEMENT.

The great disadvantage of inorganic binders is that they all add ash to the fuel. This means freight on just so much noncombustible material, less heat return for a given weight of fuel consumed, and an added amount of ash on the grate. All briquets made with inorganic binders are weak when first pressed and strengthen only gradually. Inorganic binders possess the advantage that they are not volatile, and hence the briquets, even when made from a noncaking coal or lignite, will stand up well in the fire without disintegration. They also have a tendency to lessen the smoke produced. This is due to the fact that the binder enables a somewhat slower and more complete combustion to take place and does not itself contribute any smoke to the fuel.

Another slight advantage sometimes claimed for certain of the inorganic binders, such as lime, water glass, and magnesia, results from the tendency of the calcium, sodium, and magnesium to combine with the sulphur, thus diminishing the escape of the sometimes objectionable oxidation products of that substance. This action would be the same if the calcium, etc., existed in the binder in chemical combination, as it occurs in calcium resinate. (See "Rosin," p. 30.) For the purpose of testing the above-mentioned claim, a briquet was made with Indiana No. 8 coal and 4 per cent of magnesium oxide. The briquet was dried and then burned. The sulphur in the ash (determined by the kindness of Mr. Somermeier) was found to amount to 0.44 per cent. As the sulphur in the coal was 3.72 per cent, it is evident that only a small fraction of the sulphur is retained by the magnesium oxide used as a binder. The same would probably also hold true for calcium and sodium compounds. It is thought, therefore, that the advantage thus gained is not great enough to merit consideration in practice.

Evidently the disadvantage resulting from the addition of any large percentage of an inorganic binder is too great to justify its use except as a matter of great saving in cost, or as a matter of necessity, in order to hold together in the fire some entirely noncaking coal and produce a low grade of fuel therefrom.

The essential results of the tests made with the different coals and binders are assembled in the table at the end of this report, wherein is shown the percentage of binder necessary to produce a satisfactory briquet with the coal considered.

The work of the laboratory can be regarded as sufficient so far as the negative results are concerned, but in all cases where the laboratory work seemed to promise commercial results the experiments should be repeated on a larger scale.

The inorganic substances which were tested are the only inorganic materials whose use as a binder on a commercial scale seemed even so remotely possible as to warrant testing in the laboratory. A list of other inorganic substances which have been suggested as binders, or as possible constituents of binders, would include chalk, alum, ammonium chloride (sal ammoniac), copper sulphate, sodium hydroxide, sulphur, potassium nitrate, calcium chloride, etc. That all these substances are totally unfit for such purpose appears at once from a knowledge of their properties, and they were not considered further.

DETAILED DESCRIPTION.

1. *Clay.*—The tests shown in the table (pp. 51–52) were made with a good sample of potter's clay obtained through Dr. J. H. Pratt. Clay is cheaper than coal and its cost, considered as a binder, is therefore a minus quantity.

The briquets when first taken from the press were extremely weak, many of them breaking while being taken out. The full pressure could not be given, for the coal would crush through the narrow, practically closed space between the molds and the bed plate. After drying, the briquets were hard and rather brittle. In water they fell to pieces completely and quickly. In the fire they hardened and stood up well, except those made of the noncaking lignite, California No. 1, which nevertheless stood up far better than with most binders and in comparison with the usual behavior of this lignite could be called very satisfactory.

Clay was used as a binder at one of the first plants established in this country, the Loiseau plant at Port Richmond, Pa. Trouble was experienced with the press used, the briquets when first made showing weakness. This was finally overcome, but the binder was abandoned owing to the expense of drying and waterproofing the product. Briquets made at this plant with clay were said to be very satisfactory in the fire.

Any press using clay for a binder would probably have to be specially adjusted. Owing to the large addition of ash, and to the expense of drying and waterproofing the briquet, it is improbable that clay will ever prove advantageous as a binder. If used alone it

can only be for the manufacture of a poor grade of fuel, incapable of standing any exposure to rain.

Clay in connection with other binders may be regarded as an adulteration of very doubtful value to the consumer.

2. *Lime.*—Lime, or rather, milk of lime, $Ca(OH)_2$, has often been suggested as a binder, and is said to have been used. The tests shown in the table were made with calcium oxide known to be chemically pure. In these tests the lime was mixed dry with the coal, and then water was added. In some of the tests an excess of water was added and later boiled off; in others an excess of water was added and then squeezed out in the press; and in yet others only sufficient water was added to thoroughly moisten the mass. After drying, all the briquets were very weak, those in which the largest percentage of calcium oxide was used being the worst. They finally disintegrated, merely from exposure to the air.

From these tests it is difficult to understand how it is possible to use lime alone to make a briquet. For further experiments with lime see "Rosin," (p. 30).

3. *Magnesia.*—The sample of magnesia tested was a light, calcined magnesium oxide. In the tests shown in the table (pp. 51–52) the magnesium oxide was mixed with the coal and then a sufficient amount of water was added. In some tests the briquet was pressed cold and in others more or less of the water was evaporated. The results show that 3 to 5 per cent of this binder would make a satisfactory briquet, except with certain lignites. The briquets are very hard and would stand heavy pressure, but are brittle if less than 4 per cent of binder is used. In water the briquets go to pieces, though far less rapidly than those made with clay. In the fire they behaved very well, some being satisfactory even when only 2 per cent of binder was used.

In the United States magnesite, from which magnesia is obtained, is found only in California, where the production of magnesium oxide in recent years has been as follows:

Quantity and value of magnesia produced in the United States, 1901–1906.

Year.	Quantity.	Value per ton.[a]	Year.	Quantity.	Value per ton.[a]
	Short tons.			*Short tons.*	
1901	1,666	$7.56	1904	1,357	$8.22
1902	1,349	7.56	1905	1,873	9.76
1903	1,750	7.27	1906	3,714	7.56

[a] Based on value of raw magnesite, with 10 per cent added to cover cost of manufacture of magnesium oxide therefrom, being a suggestive approximation only.

The production could be greatly increased, several million tons of the magnesite being now in sight. The mineral is calcined for the

production of carbon dioxide, leaving the magnesia, which is used principally for covering steam and heating pipes, by paper mills, and in the manufacture of bricks for lining open-hearth furnaces and converters.

At the price prevailing in 1903, the cost of 3 per cent of this binder would be about 22 cents per ton of briquets produced. Three or four per cent of ash added to the fuel would not be greatly injurious, and the binder would possess an advantage over organic binders in holding the briquet together in the fire and in reducing the smoke.

The claim that the magnesia in the briquet reduces the amount of sulphur that escapes from the coal, as already pointed out (p. 23), seems to be of no practical importance.

It seemed possible that coke breeze might be briquetted with this binder, the briquets to be used in the place of coke in the furnace. Laboratory experiments on this point, however, gave unsatisfactory results, as follows:

Results of briquetting coke breeze with magnesia.

Percentage of binder.	Grade of coherence.[a]
3	3
4	3
6	4
8	4½

[a] See p. 22.

In water the briquet with 6 per cent of magnesia behaved fairly well and that with 8 per cent splendidly, but in the fire the briquet with 4 per cent was unsatisfactory, that with 6 per cent was only fair, and that with 8 per cent was very hard to ignite.

For results of experiments with mixtures of magnesia and organic binders see p. 49.

4. *Magnesia cement.*—In 1880 Dr. A. Gurlt recommended a binding material consisting of 30 parts of 45 per cent magnesium chloride, 30 parts of 93 per cent magnesium oxide, and 60 parts of water. He used 5 per cent of this material and says that it produced a stronger briquet than any other and that it adds only 2.5 per cent of ash. The statement as to the amount of ash (magnesium oxide) added is correct. The formula on examination, leaving out the water, is found to reduce to $5MgO.MgCl_2$. The evidence on which this formula was taken as the most advantageous for the cement is not stated. The results reported in the following table are based on the proportions shown for the formulas therein given:

Results of briquetting Illinois No. 11 B coal[a] with varying formulas of binder.

Formula.	Calculated for 2 per cent of magnesium oxide in the ash.			Calculated for 3 per cent of magnesium oxide in the ash.			Remarks.
	Amount of binder per gram of coal.		Grade of coherence.[b]	Amount of binder per gram of coal.		Grade of coherence.[a]	
	MgO.	$MgCl_2$ $6H_2O$.		MgO.	$MgCl_2$ $6H_2O$.		
	Gram.	*Gram.*		*Gram.*	*Gram.*		
$MgO.MgCl_2$	0.0100	0.0500	2½	0.0150	0.0750	3	
$2MgO.MgCl_2$	.0133	.0334	2½	.0200	.0500	3	Stronger than preceding.
$3MgO.MgCl_2$	.0150	.0250	2½	.0225	.0375	3	
$4MgO.MgCl_2$	.0160	.0200	2½	.0240	.0300	3	
$5MgO.MgCl_2$	.0167	.0167	3	.0250	.0250	3½	Apparently of about equal strength.
$6MgO.MgCl_2$	.0171	.0145	3	.0256	.0216	3½	
$7MgO.MgCl_2$	.0175	.0127	3	.0262	.0190	3½	
MgO	.0200	.0000	3	.0300	.0000	3½	

[a] Bituminous coal (one-half run of mine, one-half lump) from shaft near Carterville, Williamson County, Ill. For description, analysis, and tests see Bull. U. S. Geol. Survey No. 290, 1906.
[b] See explanation under "Determination of coherence" (p. 22).

In these tests the magnesium oxide was mixed dry with the coal, and then the magnesium chloride (dissolved in water) was added. As already stated, the method of testing the small briquets made does not allow of minute differences being noted, but the results showed clearly an increase of strength until the proportion given by Doctor Gurlt and represented by the formula $5MgO.MgCl_2$ was reached. On still further decreasing the proportion of the magnesium chloride the briquets apparently did not grow either weaker or stronger. Magnesium oxide is cheaper than the chloride, and in view of the results obtained there is considerable doubt as to the advantage of adding the chloride. The addition of the chloride is said to make a more quickly setting cement, and one that is more insoluble, owing to the formation of an oxychloride of magnesium, but the statement is not verified. The magnesium chloride would also have the disadvantage of losing its chlorine in the fire, and this might come off either free or combined with hydrogen as hydrochloric (muriatic) acid. In either case the resulting gas is exceedingly corrosive and would greatly injure the boiler flues. Possibly all of the chlorine would be retained by the coal ashes, but it is a matter of grave doubt.

In the fire briquets made with 3 per cent of magnesia cement of the formula $5MgO.MgCl_2$—that is, 3 per cent after calculating the formula to MgO—stood up well. In water they disintegrated after some time. It was not evident that the briquets with magnesia cement of this formula behaved any better in water than briquets made with the same ash percentage of magnesium oxide alone, if indeed they behaved so well.

Magnesium chloride is ordinarily sold in the market in the crystallized form $MgCl_2.6H_2O$. This grade is quoted at $20 per ton in large lots in New York. It is not produced to any considerable extent in this country, but should the demand arise could probably be made from the California magnesite without increasing the cost.

All the briquets made with the magnesia cement were very hard but very brittle. They would stand great pressure, but apparently would not stand rough handling, when only 5 per cent of the cement is used, as recommended by Doctor Gurlt.

5. *Plaster of Paris.*—Gypsum, the mineral from which plaster of Paris is produced, is widely distributed in the United States. In 1903 the production was 264,196 tons, valued at $4.08 per ton.

The tests shown in the table (p. 51) were made with plaster of Paris which was first mixed with the coal. Sufficient water was added to thoroughly moisten the mass, and then pressure was applied, the excess of water, if any, running out in the press. The briquets were very hard, but also brittle, and would not stand rough handling unless at least 12 per cent of binder was used. Even these were not first-class briquets. In the fire the briquet with 12 per cent of binder held together perfectly, and would have held together with a smaller percentage. In water the briquet went to pieces more rapidly than was expected.

Although even 12 per cent of plaster of Paris in a briquet would not be prohibitive as regards cost (50 cents per ton of briquets produced), it would be as regards the addition of ash, and would moreover cause a much slower combustion of the briquet. A briquet with 6 per cent shows considerable coherence and might be satisfactory for some purposes. For results of experiments with mixtures of plaster of Paris and organic binders see page 49.

6. *Portland cement.*—In 1903, 22,342,973 barrels of Portland cement, weighing 400 pounds gross each, were produced in the United States. The average value per barrel was $1.24, and allowing 20 pounds tare for the barrel, the value per ton was $6.52.

The sample of Portland cement tested was obtained from Mr. Richard L. Humphrey and was a mixture of seven well-known brands, constituting what has been termed typical cement. In the first tests made the cement was mixed with the coal, then an excess of water was added and largely boiled off, after which the coal was pressed. The results not being satisfactory, in subsequent tests less water was added and the mixture was not heated, but the results were only a little better. In the fire briquets with 12 per cent of binder held together well, and a smaller percentage would have been sufficient. In water the briquets went to pieces somewhat more rapidly than those made with plaster of Paris.

This binder is more expensive and certainly no better than plaster of Paris. For results of experiments with mixtures of Portland cement and organic binders see page 49.

7. *Natural cement.*—In 1903 the production of natural cement in the United States was 7,030,271 barrels, of 300 pounds gross weight each. The average value was $0.522 per barrel, equivalent to $3.73 per ton, allowing 20 pounds tare for the barrel.

The tests were made with a sample from Louisville, Ky., which was mixed dry with the coal and then sufficient water was added before pressing. The results were very nearly the same as with Portland cement, the briquets being hard and brittle. In the fire the briquets held together excellently, but in water they would not stand up particularly well. Natural cement would make a cheap binder but would have to be used in such large quantity as to be very objectionable.

8. *Slag cement.*—In 1903, 525,896 barrels of slag cement, of 380 pounds net weight each, worth $1.03 per barrel, equivalent to $3.42 per ton, were manufactured in the United States. Tests were made with slag cement as with the other cements, the results indicating its inferiority to either the Portland or the natural cement as a binder for coal slack.

9. *Water glass.*—Water glass, or sodium silicate, is produced to a considerable extent in the United States, 32,651 tons having been manufactured in 1900, with an average value of $12.74 per ton.

It is said that this material will make coherent briquets when 0.75 to 1 per cent is used. Two different samples were tested. The requisite amount was dissolved in hot water and mixed with the coal, any large excess of water was boiled off, and then the briquets were pressed. The results were unsatisfactory even when 12 per cent of binder was used. The experiments were then repeated with less water and no heat, but the results obtained were no more satisfactory. When the sodium silicate was analyzed one sample was found to contain only 86 per cent of the requisite amount of silica and 13.4 per cent of the requisite amount of sodium required by the formula for the normal silicate (Na_4SiO_4). The other sample, which behaved only a little better, showed on analysis 11.1 per cent of Na_2O and 27.4 per cent of SiO_2. These poor analyses may account to some extent for the lack of success obtained with the water glass, but the results are apparently sufficient to show that it is not suitable for use as a commercial binder.

ORGANIC BINDERS.

WOOD PRODUCTS.

10. *Rosin.*—In 1900, 300,000 tons of rosin, valued at $17.02 per ton, were produced in the United States. Of this amount, according to the Census report, only 7.6 per cent was used for domestic consumption. In 1905 the price of rosin, for even the lower grades, A to C, had risen to $29 per ton.

Rosin consists mainly of abietic acid or similar isomeric acids or anhydrides. The formula of this acid is given as approximately $C_{40}H_{56}O_4$, and its acid equivalent as 145 to 185. This means that if calcium oxide is used to neutralize the acid 0.0725 to 0.0925 gram should be added to 1 gram of the rosin to form calcium resinate.

The density of rosin ranges from about 1.07 to 1.08. Rosin softens at 80° C. and melts to a limpid liquid at 100° C. The melting point of abietic acid is stated to be 165° C. Rosin is entirely soluble in carbon disulphide.

The sample of rosin tested melted at 100° C. The tests made are shown in the table (pp. 51–52). The briquets withstood exposure to the weather well and, except those made with lignites, were satisfactory in the fire, though inclined to smoke.

An attempt was made to see if the addition of lime would improve the binding qualities of the rosin. Three grams of rosin mixed with 0.25 gram of lime melts to a thicker mass, more brittle than the rosin alone. If the amount of lime is increased to 0.50 gram the brittleness is very much increased. Experiments made on Illinois No. 6 B coal, with varying proportions of lime and rosin, gave the following results:

Results of briquetting Illinois No. 6 B coal[a] with varying proportions of rosin and lime.

	Percentage of rosin used.			
	2.	4.	6.	8.
First series:				
Lime added....gram..	0.033	0.067	0.1	0.133
Grade of coherence[b].	2	3	3½	3½
Second series:				
Lime added....gram..	0.066	0.134	0.2	0.266
Grade of coherence.	2	2½	3	3

[a] Bituminous coal from Coffeen, Montgomery County. For description, analysis, and tests see Bull. U. S. Geol. Survey No. 290, 1906.
[b] See p. 22.

As 20 grams of coal were used the lime added in the first series was just sufficient to react with the rosin. The increase of lime appears from the above results to be detrimental, and the experiments were therefore not carried further. It appears that 6 per cent of rosin will be necessary to produce a satisfactory briquet with most coals, and inasmuch as rosin is now worth about $29 per ton its use as a binder is unprofitable. Nor is it likely that it will again become cheap enough to permit its use as a binder, either alone or in combination with other materials, such as tar.

11. *Pitch.*—Owing to fluctuations in the price of rosin, pitch, which is a mixture of rosin and tar, is variable in cost. In 1905 a good grade of navy pitch was quoted at about $35 per ton in St. Louis. The sample of pitch tested was of this grade. For the results of the tests made see table on pages 51–52.

Only 3 or 4 per cent of this pitch is necessary to produce a satisfactory briquet. The briquets stood the weather well and, except those made with the lignites, proved satisfactory in the fire.

The improvement of rosin as a binder by the addition of tar might have been predicted from the principles laid down, for rosin alone is too brittle to produce a tough briquet with a low percentage of binder,

and thinning the rosin with a heavy oil, such as tar, thus making it less brittle, would doubtless be advantageous. However, even where only 3 per cent of pitch is necessary to produce a satisfactory briquet its cost will probably always forbid its use.

12. *Pine-wood tar.*—No accurate data as to the amount of tar produced in the United States could be obtained. The census of 1900 reported 84 wood-distillation plants, but these were mostly using hard woods. The tar produced should be from 4 to 10 per cent of the weight of the hard wood used, but no record of the output was made, the tar being mainly burned under the retorts. The number of distillation plants in the South using pine wood has been considerably increased since the census of 1900, and plants have also been erected to use fir in the northwest. Both pine and fir yield much larger percentages of tar than the hard woods, and it may be that in the future the tar obtainable from these sources will be available for briquetting plants in neighboring sections of the country. The census for 1900 showed exports of 36,535 barrels of tar and pitch, valued at $77,082, or $15 per ton. Pine tar is quoted at 6 to 10 cents per gallon, equivalent to $13.80 to $23 per ton.

In the distillation of wood various grades of oils and tars are produced, depending both on the wood used and on the manner of distillation. An examination of representative samples of these various grades was undertaken in order to determine their value for briquetting purposes and also to determine how the product could best be made suitable for such purposes.

A solid pine-tar residuum, obtained from Summerville, S. C., was designated 12 A. The final results of the tests made with this binder are shown in the table (pp. 51–52). All the briquets except those made of lignite behaved satisfactorily in the fire. The pitch softened at 80° to 90° C. to a very sticky mass that apparently should bind well, but some of the briquets, even with 10 and 12 per cent of the binder, were too brittle, although they were sufficiently hard. The poor results with this binder were attributed to the high percentage of carbon in the pitch and to the failure of the pitch to spread well over the grains of coal. The pitch dissolved readily in either wood-tar creosote or coal-tar creosote. The following tests were made:

Results of briquetting Arkansas and Illinois coals with varying proportions of pine-wood tar and creosote oil.

Coal.	Binder (per cent).			Grade of coherence.[a]
	Pine-wood tar 12 A.	Wood creosote oil.	Coal-tar creosote oil.	
Arkansas A	5	2	....	4½
	5	....	2	4½
Illinois No. 11 B	6	2	....	4
	6	....	2	4

[a] See p. 22.

As was to be expected, these briquets smoke, but they stand up satisfactorily in the fire. The experiments show the improvement which may be made by thinning a pitch to the proper consistency. This holds also for coal-tar pitches, as will be seen later.

The pitch here discussed is a waste product, but being produced at only a few plants is not available in quantity.

A sample of very thick pine-wood tar, obtained from Cheraw, S. C., was designated 12 B. Its flowing point was 45° C. and only 3 per cent was volatile below 270° C., the volatile portion being mostly water. This tar had a density of 1.07. The results of the experiments made with it are summarized in the table (pp. 51–52).

The briquets produced some smoke, but were satisfactory in the fire except when made with lignite. They stood the weather well. This tar may prove an available binder for some briquet plants. It is obtainable at many wood-distillation plants at prices ranging from $15 to $20 per ton, and as only 3 to 4 per cent is necessary to produce a satisfactory briquet with most coals the binder would range in price from 45 to 80 cents per ton of briquets produced.

Another sample, of a slightly more mobile tar than 12 B, obtained from the same plant, was designated 12 C. Its flowing point was 42° C. and its density 1.05. About 14 per cent of this tar distilled below 270° C. The results of the experiments with it are given in the table (pp. 51–52). This tar is obtainable from any of the wood-distillation plants that could furnish tar like the sample 12 B, and would command about the same price. It contains a little more of the low-boiling oils—that is, those distilling below 270° C.—than sample 12 B, and requires about 1 per cent more of the tar to produce a satisfactory briquet.

A sample of pine tar obtained at St. Louis, Mo., was designated 12 D. It was liquid at 20° C. and had a density of 1.14. On distillation about 10 per cent came off below 200° C. and 25 per cent below 270° C. The following experiments were tried:

Results of briquetting Illinois No. 6 B coal with binder 12 D.

Percentage of binder.	Grade of coherence.[a]
2	3
4	3
6	3
8	3
12	4

[a] See p. 22.

The tar was evidently too liquid to produce satisfactory briquets. The residue left after distillation at 270° C. was then tested and gave a satisfactory briquet with Illinois No. 6 B coal when only 4 per cent of binder was used.

Another sample of pine-wood tar, obtained from a wood-distillation plant at Dunbar, S. C., was designated 12 E. It was found that about 5 per cent of this tar would produce a satisfactory briquet with Illinois No. 6 B coal.

Another sample of pine-wood creosote, obtained from Cheraw, S. C., was designated 12 F. This sample was liquid at 20° C. and had a density of 1.12. On distillation about 20 per cent by volume came off below 112° C., the distillate being mostly water, and 21 per cent more came off below 270° C. At 310° C. the residue swelled up and frothed over. The briquets made with this binder were not satisfactory, the reason being that the creosote was so thin that the briquets were easily crushed. They smoked in the fire, gave off the odor of creosote, and did not stand up well. The residuum left after the distillation of the creosote had been carried to 270° C. was tested with Illinois No. 6 B coal, the coherence being 3 and 4 with 6 and 8 per cent of binder, respectively.

A sample of pine-wood creosote, obtained from a plant at Dunbar, S. C., designated 12 G, was not tested, being similar to 12 F, with which no satisfactory results could be obtained. Another sample of turpentine oil obtained from the same plant, designated 12 H, was evidently of no value for briquetting purposes.

13. *Hard-wood tar.*—The sample of hard-wood tar examined was a rather thin liquid even at the ordinary temperature, and could not therefore make a sufficiently hard briquet. It had a density of 1.10. The following tests were made:

Results of briquetting Illinois No. 6 B coal with hard-wood tar.

Percentage of binder.	Grade of coherence.[a]
2	2
4	2
6	3
8	3
12	3½

[a] See p. 22.

On distillation below 112° C. the tar gave off 8 per cent of water; from 112° to 270° C. it yielded 44 per cent more of a light oil and of reddish paraffin oils. On testing the residue a satisfactory briquet was obtained with Illinois No. 6 B coal when 8 per cent was used as a binder. It is concluded, therefore, that the residue left from hard-wood tar after distillation to 270° C., where it is obtainable, could be used advantageously for briquetting.

14. *Fir tar.*—The sample of fir tar tested was obtained from a wood-distillation plant in the State of Washington. On distillation the tar gave off 8 per cent below 270° C. The results of the tests

are shown in the table (p. 51). As will be seen, the tar produces satisfactory briquets when 6 per cent is used.

Concerning the use of wood tar in general for briquetting, the conclusions to be drawn are that the distillation of the tar should in general be carried to 270° C., and the residue, which will be either a thick tar or a soft pitch, should be used. The briquetting qualities of a tar thus prepared will vary considerably with the source of the tar. Pine tar is best, about 4 per cent being required; fir tar comes next, about 6 per cent being required; and lastly, hard-wood tar, about 8 per cent being required to produce a satisfactory briquet. The work has not been extended to a sufficient number of samples of tar to make the above conclusions as regards the percentage of each tar required absolutely certain, but the percentages given will serve as the basis for a rough estimate of the cost of wood tar as a binder. In some localities this product might compete successfully with other binders.

15. *Wood pulp.*—The claim has been made that cellulose, which is the main constituent of prepared wood pulp, has binding properties, but a few experiments point to the conclusion that its use is wholly impracticable. Possibly the term was confused with lignocellulose, the lignone groups affording the main constituents of the sulphite liquor discussed in the next section.

16. *Sulphite liquor.*—In the manufacture of paper, wood pulp is treated with sulphurous acid to remove certain lignone groups, which combine with the SO_3H and are then removed in the waste water, in which they are soluble. This waste liquor, amounting to ten or twelve times as much as the cellulose fiber produced, yields on evaporation an average of 9 to 10 per cent of solid residues. Roughly, therefore, the amount of this solid waste material is equal to the amount of cellulose obtained. According to the United States Census report for 1900 the amount of sulphite fiber produced was 416,037 tons, and the estimate indicates that there was an equal production of the waste lignone complex.

Not only is this liquor a true waste material, finding at present no market, but its production is a great nuisance, for it very seriously pollutes the streams on which the mills are situated and gives rise to much trouble. Its cost, therefore, would be represented solely by the cost of getting rid of the excess of water and by the freight to the briquetting plant. The water could be removed by evaporation, during which process the complex groups are to some extent broken down, sulphur and sulphur compounds being formed and some of them escaping. Of the solid residue left from evaporation 20 per cent is inorganic material and 80 per cent is organic. An ultimate

analysis of the lignone complex groups shows, according to Cross and Bevan, carbon, 50.22 to 56.27 per cent; hydrogen, 5.22 to 5.87 per cent; sulphur, 5.52 to 8.80 per cent.

Efforts have been made by various investigators to separate the lignone complex groups from the water by precipitation instead of by evaporation. It is possible that some process of settling and filtration may recover the desired gummy residues without going to the expense of evaporating the water, but the processes so far devised are as yet unsuccessful on a commercial scale.

The sample of sulphite liquor examined was obtained from Detroit, Mich. On evaporation it showed a dry residue of 11.8 per cent. This residue, of course, does not melt but chars and decomposes if heated to a high temperature. Before evaporating quite to dryness the residue is a very sticky, gummy mass, easily soluble again in water. The original liquor was evaporated to about one-third of its bulk and when in this condition was used in the following tests:

Results of briquetting California lignite[a] and Illinois coal with sulphite liquor.

Percentage of binder.	Grade of coherence.[b]	
	California No. 1.	Illinois No. 6 B.
2	....	2
4	....	2½
6	....	3
8	....	3½
10	3½	4
12	4	4½

[a] Lignite from Tesla, Alameda County. For description, analysis, and tests see Bull. U. S. Geol. Survey No. 290, 1906.
[b] See p. 22.

The briquets from Illinois No. 6 B coal, with 10 per cent binder, and from California No. 1, with either 10 or 12 per cent binder, were satisfactory in the fire. The briquets made from the California lignite show the good effect of using a binder which does not volatilize or melt, for this coal is one of the most difficult of all the coals with which to obtain satisfactory results in the fire. In water, of course, the briquets will go to pieces rapidly.

It must be remembered that the above percentages of binder refer not to the dry residue from the sulphite liquor, but to the liquor itself when concentrated only to one-third of its bulk. To compare the results with the dry material the percentages must be divided by three. In other words, we have from the paper mills each year 1,200,000 tons of waste material which will produce coherent briquets when 10 to 12 per cent of it is used as a binder. The drawback to its use is the fact that the briquets are not waterproof, and a few

preliminary experiments were made in an endeavor to overcome this difficulty, with the following results:

Results of briquetting California lignite and Illinois coal with varying proportions of sulphite liquor and other binders.

Coal.	Binder (per cent).			Grade of coherence.[a]	Fire test.	Water test.
	Sulphite liquor.	Waterproofing constituent.				
		Material.	Amount.			
California No. 1 (lignite)	8	Pitch 39	4	4	Fair	Fair.
	8	do.	8	4	O. K.	
Illinois No. 6 B	6	Coal-tar creosote	4	3½	O. K.	
	6	Asphalt tar	4	4	O. K.	Fair.
	6	Pitch 39	4	4	O. K.	Fair.

[a] See p. 22.

These experiments indicate that oils and pitches mixed with the sulphite liquor will render the briquet more or less waterproof, depending on the extent and character of the added constituent. The whole problem is an important and promising one and deserves further investigation.

SUGAR-FACTORY RESIDUES.

17. *Beet pulp.*—Several samples of beet pulp (a waste product) were examined and carefully tested in the hope that they might contain sufficient starchy or sugary material to serve as a binder. The results showed that the pulp could be of no use whatever for this purpose. Details of the tests need not therefore be given.

18. *Lime cake.*—The sample of lime cake examined proved to be practically pure calcium carbonate, which could be of no possible use in briquetting.

19 and 20. *Beet-sugar molasses and cane-sugar molasses.*—The binding power of molasses is said to be due to pectin, which is a body closely related to mucilage and has the constitution of a typical lignocellulose. To a less extent the binding power is due to sugar. Molasses contains only about 10 per cent of ash. From 1 to 1.5 per cent of molasses in water is said to be sufficient for binding, but the experiments do not verify the statement. Three samples of beet-sugar molasses were examined—19 A, 19 B, and 19 C. Samples 20 A and 20 B were cane-sugar molasses. The moisture and ash were determined as follows:

Moisture and ash in beet-sugar and cane-sugar molasses.

	Beet-sugar samples.			Cane-sugar samples.	
	19 A.	19 B.	19 C.	20 A.	20 B.
Moisture per cent	12.5	13.8	21.8	27.3	27.5
Ash do	8.1	10.1	9.9	6.3	5.7

Tests in briquetting Illinois No. 6 B coal with these samples gave the following results:

Results of briquetting Illinois No. 6 B coal with varying percentages of beet-sugar and cane-sugar molasses.

Percentage of binder.	Grade of coherence.[a]				
	19 A.	19 B.	19 C.	20 A.	20 B.
2	3	2	......	......	......
4	3	3	2	$2\frac{1}{2}$	2
6	3	3	3	3	3
8	3	3	3	3	3
12	3	3	3	3	3

[a] See p. 22.

The coherence of the briquets did not seem to be increased by using more than 6 per cent of molasses. The failure to obtain good briquets with smaller percentages or to obtain satisfactory briquets even when the higher percentages were used is hard to explain. Heating the briquets to a higher temperature, even to 150° or 160° C., did not seem to improve them. Their behavior in the fire could not be regarded as very satisfactory. In water they fell to pieces.

Some experiments were made with lime and molasses and also some attempts to waterproof these briquets, but no very satisfactory results were obtained. The use of molasses as a binder needs further investigation before it is finally classed as being of no use for briquetting, but so far it would seem to be without commercial value for this purpose.

The census report for 1900 showed that there were 3,551,856 gallons of this molasses produced, valued at $25,102 for the portion sold. Much of it went to waste.

STARCH.

21. *Cornstarch.*—In the tests of cornstarch it was first necessary to determine if heating the starch with water to a paste, thus forming dextrin, before mixing it with the coal was essential, or if the change of starch into dextrin would take place as well when the starch was first mixed with the coal and the mixture then moistened and heated. The experiments showed that the latter procedure was fully as effective. Starch was tested more particularly with the lignites, because it does not evaporate before burning, and hence would hold the lignite together in the fire. The results of the tests are shown in the table (pp. 51–52). In all the tests the behavior of the briquets in the fire was far more satisfactory than if pitch or a similar binder had been used. Starch possesses the advantage over such binders that it adds no smoke-producing material to the coal.

In water these small starch briquets fell to pieces in a few minutes, and the next endeavor was to waterproof them. Many attempts were

made to accomplish this end by immersion in oil. The experiments indicated that any oil would waterproof the briquet when externally applied, but asphalt tar, which was the thickest oil tested, gave the best results. It is doubtful if external waterproofing with a thick oil would ever be commercially successful, owing to the cost and difficulty of manipulation, but a thin oil, such as crude petroleum, might answer. At any rate, laboratory tests with small briquets can not finally decide the point, and the experiments should be conducted on a larger scale.

An endeavor was also made to waterproof by mixing the coal and starch with some of the oils before briquetting. For this purpose Hoffman's petroleum, Kansas crude oil, coal-tar creosote, asphalt tar, water-gas tar pitch, coal-tar pitch, and hard-wood tar were used under varying conditions and with varying percentages both of the starch and of the oils. The experiments indicate that the presence of crude oil or tarry liquids is detrimental to the action of the starch, both as to coherence and in the fire. But the binding power of the starch, though somewhat diminished, was nevertheless still very great, and it is probable that a briquet with 1 per cent of starch and 8 per cent of a heavy crude oil, or a less percentage of oil residue, would prove satisfactory. It is possible that in some places such a combination might prove the cheapest and most satisfactory binder obtainable. Pitches did not seem to injure the action of the starch, but unless a small percentage of pitch is found to waterproof there would be nothing gained by the combination. The experiments made did not seem to indicate that a small percentage of pitch with starch would give satisfactory results in the weather, but this point should be tested on a larger scale.

A patent for the use of starch as a binder was issued in 1858, in England, to John Piddington. He used 36 pounds of starch and 8 per cent of water per ton of coal.

The objections to starch as a binder are that the briquets do not immediately harden, and that they will not stand exposure to the weather unless made waterproof. The advantages of starch as a binder are its cheapness, its wide availability, the fact that it introduces no smoke, and the fact that, being nonvolatile, it holds the coal together well.

As shown by the census report for 1900 the amount of starch produced in the United States during that year was 297,803,139 pounds. Of this amount 247,051,744 pounds was made from corn as raw material, the average price of the starch being 2.5 cents per pound. It is of course not necessary that starch to be used as a binder be pure, and a far better idea of its cost for this purpose can be obtained by considering the cost of the raw material.

The raw materials available in the United States are corn, wheat and other small grains, Irish potatoes, sweet potatoes, cassava, and spoiled products containing starch. The starch from wheat and other small grains is more expensive than that from corn. Cassava, yielding 4 to 5 tons per acre and containing about 25 per cent of starch, offers a very cheap source of starch, but in the United States it can not be grown far north of Florida.

In 1900, 231,106 tons of corn were used for the production of cornstarch, the average price paid being $11.78 per ton. Corn contains 60 to 65 per cent of starch. The factories extracted on the average 53.4 per cent, and the cost of this starch in the crude condition is therefore $18.85 per ton. The only preparation necessary would be fine grinding.

The price of raw cornstarch may be estimated at $20 per ton, based on the census report for 1900, and inasmuch as only 0.5 to 1 per cent of this material is required to make a coherent briquet, it follows that the cost of starch binder of this kind per ton would be only 10 to 20 cents. The briquets would not stand rain, but would prove perfect if kept under cover. It seems that starch briquets, only slightly waterproofed, might be used during the dry season in certain sections of the West. If more thoroughly waterproofed with heavy crude petroleum oils they might be generally used. The crude petroleum would increase the fuel value of the briquet almost sufficiently to pay for itself. It seems, therefore, that further experiments with starch on a larger scale are desirable.

22. *Potato starch.*—Properly chosen varieties of the sweet potato contain about 22 per cent of starch and the yield per acre is large. Small, unmarketable potatoes may be used. The sweet potato is available in many parts of the United States.

The Irish potato is widely distributed, and starch factories consumed 118,000 tons in 1900, paying an average of $5.90 per ton and obtaining an average of 14.3 per cent of starch. As a rule only unmarketable potatoes were used and this accounts for the low percentage of starch obtained, the average yield of Irish potatoes being 18.2 per cent of starch, and some varieties giving as high as 25 per cent. On the basis of 18 per cent available starch, the raw starch obtained from this source is worth $32.75 per ton.

Usually, therefore, starch obtained from potatoes would be more expensive than that obtained from corn. A number of tests were made to see if the action of the two starches is similar. No difference in the coherence of the briquet or in its behavior in the water or in the fire was detected.

SLAUGHTER-HOUSE REFUSE.

Slaughter-house refuse, which is now largely made into glue, has been so often suggested as a binder that its cost was investigated. The census of 1900 showed that 34,750 tons of glue were produced, valued at $155 per ton. The price is therefore prohibitive and no experiments were made with this material.

TARS AND PITCHES FROM COAL.

Preliminary considerations.—The work done at the briquetting plant under the direction of Dr. J. H. Pratt had shown that there was great variation in the value of various coal-tar pitches for briquetting purposes. That work had also shown that coal-tar pitch would be one of the most important binders to be considered. An endeavor was made, therefore, to study the various grades of coal tar and the pitches therefrom, with the idea of improving the pitches and of establishing some method of examination which might reveal their value without the necessity of an actual briquetting trial.

The total production of coal tar in the United States in 1903 was 62,964,393 gallons, valued at $0.0349 per gallon, or $7.27 per ton.

On distillation coal tar is divided into several fractions which are more or less clearly defined. By further distillation these fractions are separated more completely and find their way to the market as illuminating oils, naphtha, creosote, etc. They consist of a very large number of chemical compounds. The manner in which coal tar is fractionated varies at different works, but as illustrative, it may be said that the ammoniacal liquor distils first, then the first light oils, boiling below 110° C. The second light oils come off at 110° to 170° C., the carbolic oils at 170° to 225°, the creosote oils at 225° to 270°, the anthracene oils at 270° to 360°, and lastly the pitch is left behind as a residue.

None of the oils coming off below 270° C. are useful in briquetting. The anthracene oils, which consist of a large number of different compounds, should not, however, be entirely distilled from the pitch if it is desired to use the pitch for briquetting. Nearly all the various constituents of both the pitch and the anthracene oils except the free carbon are soluble in carbon disulphide. Constam and Rougeot[a] examined 33 pitches obtained from various sources, and found the amount of carbon-disulphide extract to range from 60.43 to 91.22 per cent and to average 76.3 per cent. They also found the value of the pitch for briquetting purposes to be proportional to the amount of carbon-disulphide extract. The results obtained by the writer lead to the same conclusion, except that the free carbon (that is, the insoluble portion) is believed to be not only inert but detrimental to

[a] Zeitschr. f. angew. Chemie, vol. 17, no. 26.

the pitch, indicating that the increase in the value of a pitch for briquetting purposes is somewhat greater proportionally than the increase in the percentage of extract obtainable. The free carbon seems to prevent the pitch from spreading easily over the grains of coal, and owing to its very finely divided condition itself offers a very large surface for the absorption of pitch.

A pitch has no true melting point, but owing to the large number of different chemical bodies which it contains, softens only very gradually. This softening point of the pitch has a marked influence on its use in briquetting, for the pitch must either be so brittle that it can be broken finely and mixed with the coal as a solid, or it must be melted and distributed as a liquid. Many pitches soften at so high a temperature that they can not be efficiently used except by heating above 100° C. The pitch must therefore be adapted to the briquetting machine in which it is to be used. Many methods of determining the softening point of a pitch have been suggested, but most of them are either too troublesome for practical use or not accurate. In the experiments here recorded the flowing point of the pitch was used as an index of the temperature at which it softened. This point was determined by placing about 3 cubic centimeters in the bottom of a test tube one-half inch in diameter and inserting the tube in a bath. The temperature of the bath was raised until, on taking out the tube and inverting it, the pitch flowed 1 inch down the tube in fifteen seconds.

In ascertaining the value or suitability of a given pitch or tar for briquetting purposes three determinations are necessary:

1. The pitch or tar is distilled and all oils coming off below 270° C. are rejected as being of no value in briquetting.

2. The flowing point of the portion to be used in briquetting is determined. This should generally be not less than 70° C.

3. The pitch is extracted with carbon disulphide. The smaller the amount of residual carbon the more satisfactory the pitch.

It should be borne in mind that the higher the flowing point of the pitch the more satisfactory it will prove in the fire when used with coals that do not cake readily. If the pitch has too high a flowing point to be workable with the briquet machine at hand, it could be softened by the addition of a high-boiling coal-tar oil (above 270° C.) or of very soft pitch. Coal-tar creosote could be used, but its boiling point is too low to make its use in all respects satisfactory.

23. *Blast-furnace tar.*—As it was impossible to learn whether blast-furnace tar and the similar material known as shale tar are produced in the United States, no experiments were made with them.

24. *Producer-gas tar.*—Two samples of producer-gas tar were examined. The first, designated 24 C, after pouring off the water, gave on distillation, water, 30 per cent; oils below 270° C., none;

oils at 270 to 330° C., 6 per cent. From 330° the thermometer jumped suddenly to 370° and the distillation was stopped. The residue gave with Illinois No. 4 coal a satisfactory briquet when only 4 per cent was used as a binder.

The next sample, designated 24 D, was tested after boiling off the water. The result showed a satisfactory briquet with Arkansas No. 7 A coal when 4 per cent was used, but a larger percentage is necessary with most other coals and probably 8 per cent would be necessary for most lignites.

The tar obtained, when freed from water only, is rather too liquid to produce the best quality of briquet. But the removal of only about 6 per cent of oils raises the flowing point of the tar to about 70° C. and the residue appears, as above seen, to be excellently fitted for briquetting purposes. The amount of carbon-disulphide extract obtainable from the residue was not determined. It should not be large, for the temperature at which the tar is made is comparatively low. This is probably the cause of the superior binding power of the pitch.

The amount of this tar obtainable and its market value are questions for future determination.

25. *Illuminating-gas tar.*—About 25 per cent of the illuminating gas produced in the United States is made from coal, and the tar resulting from the process amounts to about 5 per cent of the coal coked. The census report for 1900 gives the production for 1899 as 67,094 tons. In 1903, 61.4 per cent of the coal tar made was produced in gas works. The average value of this tar as distinct from other coal tars is not obtainable, and $7.27 per ton, the average value of all coal tars for 1903, is therefore accepted as approximately correct for gas tar.

This tar is too liquid to produce good briquets. The oils coming off below 270° C. should be disposed of. The residue, equaling 70 per cent of the total, would cost $10.40 per ton, if the sale of the low-boiling oils could be made to pay the expense of the distillation and the profit thereon.

Pitches 28 A, 28 B, 28 C, 28 D, 28 E, 28 F, and 28 I, obtained from this tar, were examined, and the percentages determined as necessary to make satisfactory briquets are shown in the table (pp. 51–52).

26. *By-product coke-oven tar.*—In 1903, 38.6 per cent of the total coal tar produced (24,296,536 gallons) was produced in by-product coke ovens. The census report for 1900 shows that in 1899 only 3.33 per cent of the total coal coked was coked in by-product ovens. Consequently the amount of coal tar from this source could be enormously increased.

This tar is obtained by distillation at a high temperature, and therefore contains more fixed carbon than tar from illuminating-gas

plants. About 60 per cent of the tar from an Otto-Hoffman oven is pitch.

The tar is too liquid to be used directly for briquetting. The results with pitches 28 G and 28 H, made from coke-oven tar, are shown in the general table (p. 51).

27. *Coal-tar creosote.*—The principles governing the use of binders make it appear useless to test coal-tar creosote alone. It is too thin a liquid to make coherent briquets and of too low a boiling point to give satisfactory results in the fire. This creosote could be used to thin a pitch whose boiling point is too high, when such use is advantageous. It could also be used to waterproof a binder that would not stand the weather; but this could be done as well with a crude oil of low specific gravity, and the cost would be less. Coal-tar creosote is worth about 6 cents per gallon.

28. *Coal-tar pitches.*—The pitch designated 28 A was obtained by Dr. J. H. Pratt, who called it pitch C in his report.[a] This pitch flowed at 100° C., and the behavior of the briquets in the fire was satisfactory.

The pitch designated 28 B was obtained through Dr. Pratt and was by him designated, in his report, pitch D. This pitch had a flowing point of 127° C. It was used in making a very large number of tests on the comparative action of different coals with the same binder.

The pitch designated 28 C was used to briquet 50 tons of Arkansas semianthracite slack, about 6.5 per cent being used. This pitch had a flowing point of 100° C. It proved too soft for use with a pitch cracker on a summer day.

The pitch designated 28 D was used to briquet 200 tons of Arkansas semianthracite slack, about 6.5 per cent being used. This pitch had a flowing point of 120° C. and was sufficiently brittle for use on the hottest day. It gave a carbon-disulphide extract of 67.75 per cent.

The pitch designated 28 E had a flowing point of 100° C.

The pitch designated 28 F was very soft, having a flowing point of 68° C., and did not prove as efficient a binder as its appearance indicated. No further examination was made to determine the cause of the trouble.

The pitch designated 28 G was a soft coke-oven pitch obtained from tar produced in the Semet-Solvay process. It had a flowing point of 95° C. and yielded about 86 per cent of carbon-disulphide extract.

The pitch designated 28 H was a harder coke-oven pitch from the same source as 28 G. It had a flowing point of 100° C. and gave 81.50 per cent of carbon-disulphide extract. The briquets were possibly a little stronger than those made with the soft coke-oven pitch.

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[a] Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; Bull. U. S. Geol. Survey No. 261, 1905, p. 134.

The pitch designated 28 I was received through Dr. Pratt, who called it pitch X in his report.[a] It had a flowing point of 190° C., being very hard and brittle. The carbon-disulphide extract was 63.2 per cent. A large number of tests were made with this pitch when determining the qualities of binders in general in order to learn why this grade was so poor a binder. This seemed to be due to two causes—(1) the large amount of contained free carbon (36.8 per cent), and (2) the high softening point. At 100° C. the binder did not melt sufficiently to spread over the grains of coal to the best advantage.

To test this latter point the pitch was mixed with wood creosote 12 F, which did not itself possess sufficient binding power. Two hundred grams of pitch was mixed with 100 grams of the wood creosote and heated with stirring until thoroughly mixed. The resultant pitch, which was brittle enough to be pulverized if kept cool, was then tried with a number of coals and compared with the original pitch. The results from this mixture, designated 28 J, are shown in the table (pp. 51–52). It will be noted that in all the tests 4 per cent more of the original pitch than of the mixture was required, thus confirming the diagnosis of the trouble.

None of the coal-tar pitches gave coherent briquets with less than 6 per cent, and with many of them 7 or 8 per cent was required. The reason why a coal-tar pitch will not briquet if less than 6 per cent is used is that it contains a comparatively large amount of carbon. The residue from producer-gas tar made satisfactory briquets with 4 per cent, and this result was doubtless due to the fact that such tar contains little free carbon.

The cost of coal-tar pitch per ton may be taken as $11; therefore the cost of the binder per ton of briquets produced ranges from 66 to 88 cents. The briquets when properly made will stand exposure to the weather well. They will stand up satisfactorily in the fire if the coals cake at all readily. With noncaking coals the briquets would not prove satisfactory in the fire. This binder does not cause an undue amount of smoke.

NATURAL ASPHALTS.

Asphalts grade almost imperceptibly into heavy, thick petroleum oils. The designations used by Eldridge[b] have been followed in this discussion. Wurtzilite, nigrite, ozocerite, and grahamite occur in the United States, but not in deposits profitable to mine.

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[a] Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; Bull. U. S. Geol. Survey No. 261, 1905, p. 134.

[b] Eldridge, G. H., Origin and distribution of asphalt and bituminous rock deposits in the United States: Bull. U. S. Geol. Survey No. 213, 1903, pp. 296-305.

30. *Impsonite.*—Impsonite, sometimes called grahamite, is found in Oklahoma. It softens at a high temperature, but does not melt. In carbon disulphide 35 per cent or more is dissolved.

The sample tested was obtained through Dr. Pratt and was designated B 4 in his report.[a] This was tested with a lignite, as its only possible use in briquetting was considered to be to mix with a noncaking coal in rather large percentage. From 20 to 30 per cent was found to be required to hold a California lignite together in the fire. Even though the material is very cheap, the large percentage required prohibits its commercial use.

31. *Gilsonite.*—It is estimated by Eldridge that 32,000,000 tons of the asphalt known as gilsonite are now in sight in the extensive deposits that occur in Utah. He further states that the cost to mine does not exceed $1.75 per ton. The material has to be hauled a long distance to a railroad, and the present price in St. Louis is about $35 per ton. Gilsonite has a brilliant luster, burns and acts like sealing wax, and is entirely soluble in carbon disulphide. Two samples were tested.

The sample designated 31 A was black, with a brilliant luster, and flowed at about 250° C. In testing, the finely powdered material was mixed dry with the coal and heated far above 100° C. As shown in the table (p. 52) it gave a good briquet when 4 per cent was used.

The sample designated 31 B was black, with a less brilliant luster. When its flowing point was being determined it frothed out of the tube. It gave a briquet of satisfactory coherence when 6 per cent was used as a binder. The briquets are also satisfactory in the fire; and, owing to the high softening point of the binder, it would be very useful with noncaking coals. At its present price of $35 per ton, however, even 4 per cent of this binder is out of the question.

32. *Maltha.*—Small deposits of maltha, a liquid asphalt, occur in Oklahoma, Mexico, California, and Texas. In 1903 the only production reported to the Geological Survey was 58 tons from Texas, valued at $19.83 per ton.

The sample tested was obtained through Dr. Pratt and was called by him "liquid Austin asphalt." A satisfactory briquet was produced with 3 to 3½ per cent of binder. Attention is called to the fact that when as much as 8 per cent of this binder is used the briquet grows weaker instead of stronger. This is due to the low flowing point of maltha, 58° C., which causes the briquet to crush easily if an excess is used. In the fire the binder would give satisfactory results only when used with coals that cake very easily.

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[a] Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; Bull. U. S. Geol. Survey No. 261, 1905, p. 134.

The cost of this binder, 3 per cent being used, would be 60 cents per ton of briquets produced. With some coals a larger percentage would be necessary.

33 and 34. *Refined Trinidad asphalt and refined Bermudez asphalt.*—Considerable quantities of crude Trinidad and Bermudez asphalts are annually imported. In 1903 the imports of the former amounted to 129,133 tons, valued at $367,003; and of the latter 9,898 tons, valued at $48,218.

The cans in which samples were furnished for these experiments were not marked and complete identification was impossible. The softer of the two samples flowed at 115° C. and could not be powdered. It gave a satisfactory briquet when 6 per cent was used with Illinois No. 11 C (4) coal. The harder sample could be powdered, flowed at 180° C., and on testing showed a briquet that was hardly satisfactory when 8 per cent of the binder was used with Illinois No. 11 C (4) coal. If the binder had been superheated better results could probably have been obtained.

These asphalts apparently could not compete with coal-tar pitches as binders.

35. *Hard and refined asphalts.*—Bituminous sandstones, limestones, or shales occur in several States in deposits of considerable extent. These are mined, but usually the rock is used as a constituent of paving mixtures and the bitumen is not extracted. Attempts have been made to refine this rock either by distillation or by extracting the bitumen with a solvent, such as naphtha. The process does not seem to have been very successful commercially. The only production reported is 6,400 tons from California, with a value per ton of $21.87; and 877 tons from Indian Territory, with a value per ton of $17.61. No samples could be obtained, and the product is probably not now on the market.

PETROLEUM PRODUCTS.

36. *Crude oil.*—Unless they are of the consistency of maltha, crude oils are not suitable for binders, being too liquid. They might be used to advantage in waterproofing briquets made with starch, sulphite liquor, or molasses.

37. *Petroleum residuum.*—There are many grades of petroleum residuum depending on the base of the crude oil (that is, whether the oil has an asphalt base, or a paraffin base, or an asphalt and paraffin base), on the temperature at which the distillation is stopped, and on the amount of cracking to which the oil is subjected during the distillation.

In 1903, 46,000 tons of asphaltic residue, with an average value of $11.30 per ton, were produced from petroleum in California; and

2,100 tons, valued at $14.16 per ton, were produced in Texas. If 4 per cent of this material were used as a binder, the cost per ton of briquets produced would be 45 to 55 cents per ton, making this binder one of the cheapest to be had near the oil fields, when the oil contains an asphalt base. Even less than 4 per cent could be used with some coals. For the best results, the asphalt residue should flow at 90° to 100° C.

Six samples of asphalts were examined. The sample designated 37 A was shown by test to flow at 100° C., and 99.38 per cent was soluble in carbon disulphide. The tests showed that except with the lignites, 3 to 4 per cent of this asphalt would give a satisfactory briquet. With caking coals it is satisfactory in the fire.

Another sample was designated 37 B. With most coals 3 to 4 per cent of this asphalt would be required to produce satisfactory briquets.

The sample designated 37 C was received through Dr. Pratt from Caspar, Wyo., and by him was designated B 6 in his report.[a] It flowed at 95° C., and gave a carbon-disulphide extract of 99.88 per cent. A satisfactory briquet was made with 4 per cent of this binder.

The sample designated 37 D was received from Texas, and was designated B 3 in Dr. Pratt's report.[a] It flowed at 140° C., and with most coals about 6 per cent would be required to produce a satisfactory briquet.

The sample designated 37 E, a California asphalt of grade B, was designated B 1 by Dr. Pratt.[a] It did not soften sufficiently at 100° C., but if superheated a satisfactory briquet could be obtained with 8 per cent as binder.

The sample designated 37 F, a Texas asphalt, was designated B 2 by Dr. Pratt.[a] It did not soften sufficiently at 100° C. When superheated it gave a satisfactory briquet with Illinois No. 4 coal, 6 per cent of binder being used.

38. *Water-gas tar.*—The census report states that 75 per cent of the illuminating gas produced in the United States in 1899 was water gas. Petroleum oil is used in enriching this gas and is partly decomposed in the process, resulting in the formation of water-gas tar, of which 48,714,324 gallons were produced in 1899. With an average density of 1.1, this would be equivalent to 222,868 tons of tar. The tar itself is too liquid for use, but a pitch made from it was examined, as shown in the next paragraph.

39. *Water-gas tar pitch.*—The sample of water-gas tar pitch furnished to Dr. Pratt was by him designated pitch H.[a] It flows at 92° C., and with some of the coals 5 per cent proved sufficient to produce excellent briquets. The carbon-disulphide extract was 88.10 per cent. With caking coals the briquets are satisfactory in the fire. This pitch is worth somewhat less than coal-tar pitch, its value being

[a] Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; Bull. U. S. Geol. Survey No. 261, 1905, p. 134.

given approximately as $10 per ton. The cost of the binder per ton of briquets produced would therefore be about 50 cents, effecting a saving of at least 20 cents per ton over the use of ordinary coal-tar pitch.

40. *Wax tailings.*—A product known as wax tailings was received by Dr. Pratt. It is soft at ordinary temperatures and pulls into long threads. It melts to a thin liquid at about 70° C. As low as 3 per cent gives briquets of satisfactory coherence and these are also satisfactory in the fire if the coal cakes readily. The briquets could not be subjected to any pressure in the fire, and would yield to pressure if placed in a warm place. It is doubtful if they could be piled in a very hot sun. The yield of this product is said to be moderate in amount. The value is 6 cents per gallon, or about $15 per ton, and the cost of this binder would therefore be 45 to 60 cents per ton of briquets produced.

41. *Acid sludge.*—Tests of a sample of acid sludge showed that 10 to 12 per cent was necessary to make a coherent briquet. This material was distinctly acid with sulphuric acid. Its value could not be learned and therefore no further experiments were tried with it.

42. *Asphalt tar.*—The product known as asphalt tar, as obtained by Dr. Pratt, was a rather thin liquid which poured readily and produced briquets that would crush easily and would not stand up satisfactorily in the fire. This tar, if its price permitted, might be used for waterproofing briquets made with soluble binders, as starch, sulphite liquor, or molasses.

43. *Pintsch gas tar.*—Pintsch gas tar, produced by the heating of petroleum oil in iron retorts to a high temperature, is obtained as a thin emulsion in water, being too thin for use as a binder. As it is produced only in very small amounts in the United States, its further examination was deemed inadvisable.

44. *Pittsburg flux.*—The substance known as Pittsburg flux is made by heating petroleum residuum with sulphur. The sample tested was tough and sticky, would cut easily, but would not pull into threads. It melted to a thin liquid at about 195° C. In testing it was mixed with Illinois No. 11 C (4) coal and heated far above 100° C. It produced a satisfactory briquet when 8 per cent was used.

ADDITIONAL EXPERIMENTS WITH MIXTURES.

All the briquets made with inorganic binders were brittle, though very hard. Experiment had shown that when brittle pitches, etc., were used, the briquets became less brittle if a thinner pitch or oil was added. Therefore an attempt was made to improve these briquets by the addition of organic binders. For this purpose coal-tar creosote (27), asphalt tar (42), and water-gas tar pitch (39) were chosen. The results are shown in the following table:

Results of briquetting California and Illinois coals with varying mixtures of organic and inorganic binders.

Coal.	Binder.				Grade of coherence.[a]
	Inorganic constituent.		Organic constituent.		
	Material.	Per cent.	Material.	Per cent.	
Illinois No. 6 B	Plaster of Paris	6	Coal-tar creosote	4	3
	....do	6	Asphalt tar	4	4
	....do	6	Water-gas tar pitch	4	4
	Portland cement	6	Coal-tar creosote	4	3
	....do	6	Asphalt tar	4	3
	....do	6	Water-gas tar pitch	4	4
	Magnesium oxide	2	Coal-tar creosote	4	3
	....do	2	Asphalt tar	4	3
	....do	2	Water-gas tar pitch	4	3½
California No. 1	Plaster of Paris	6	.....do	8	4½
	Portland cement	6	.....do	8	4½
	Magnesium oxide	3	.....do	8	4
	....do	4	.....do	4	3

[a] See p. 22.

The briquets made with Illinois coal and water-gas tar pitch were fairly good and stood up very satisfactorily in the fire. The advantage gained, however, over the use of the water-gas tar pitch alone would not be sufficient to offset the introduction of the 6 per cent of ash with the cement or the plaster of Paris, or the cost of the magnesium oxide when that material is used. The cohesive force of the briquets made with the two binders was no greater than the sum of the cohesive force obtained with each separately. The only advantage to be gained by using such mixed binders would be an added strength in the fire. Experiments with the California lignite were therefore made as above shown. The briquets were found to be considerably improved as to their behavior in the fire by the addition of the inorganic constituent of the binder. Briquets from this coal made with pitch alone fall to pieces badly in the fire. The improvement in this regard, however, is offset by the added expense and the introduction of ash, and it is therefore considered more desirable where possible to mix such noncaking coals with caking coals before briquetting. If this is not practicable then the addition of inorganic binders might be tried as a last resort. Should the inorganic binders be used, magnesium oxide and plaster of Paris will be found to give the most satisfactory results, 3 per cent of the former being equivalent to 5 to 6 per cent of the latter.

EXPERIMENTS IN BRIQUETTING WITHOUT BINDERS.

Many experiments were made in the endeavor to obtain briquets by heating the coal without binder and then pressing. It was found that if this heating was done in a clay crucible as usual, coherent briquets could not be obtained. But if the heating was done in a small nickel crucible and the pressure applied before the coal was allowed to cool, briquets having considerable coherence were often produced. If the coal cooled after it had softened or commenced to cake, a coherent briquet could not be obtained, and even on again heating the coal it would not cohere in the press. This fact has also been noted by C. C. Catlett.[a] It was undoubtedly because of the necessary chilling of the heated coal in taking it out of the crucible that better results were not obtained by this method. The experiments show the necessity of heating the coal under pressure if briquets are to be made without a binder. The German presses for briquetting lignite coal without a binder, which heat the coal by friction produced in the molds, are undoubtedly based on the right principle.

RESULTS OF TESTS IN BRIQUETTING DIFFERENT COALS.

The results of the tests here reported should be interpreted in connection with the detailed discussion of each binder. Thus while binders 12 D, 13, 25, 26, etc., mentioned in the table which follows, are too liquid for use as a binder, the pitches or tarry residues left after distilling off the low-boiling oils from these binders will make excellent briquets, as has been already pointed out. It should be remembered, moreover, that the degree of fineness to which the coal is powdered, and also the temperature to which the mixture of coal and binder is heated, will affect the character of the briquet and the percentage of binder necessary to make it coherent. Doubtless an uncontrolled variation in these factors has caused individual results to vary, but probably not to such an extent as to affect any important conclusions to be drawn from the work.

Although many of the binders were tried with only one coal, the result permits the approximate prediction of the percentage of binder for any other coal in the table. It is not possible, however, to predict with the same certainty for the lignites, which show at times variations not susceptible of easy explanation.

[a] Eng. and Min. Jour., vol. 71, 1901, p. 329.

Results of tests in briquetting different coals, showing percentages of binder necessary to make a satisfactory briquet.

Designation of binder.		Field designation of coals and lignites briquetted.											
					Illinois.								
Material.[a]	No.	Arkansas. 7 A?.	California. 1.	Colorado. 1.	4.	5.	6 B.	7 C.	7 D.	8.	9 A.	10.	11 B.
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Clay	1	8	8				8						8
Magnesia	3	4					5						4
Magnesia cement[b]	4												4
Plaster of paris	5												12
Portland cement	6												12
Natural cement	7												14
Water glass	9												14
Rosin	10	6	6				6						6
Pitch	11	3	5				4						3.5
Wood-tar pitch	12 A	8	12				12						10
Pine-wood tars	12 B	3	8				4	3		5	5	4	3.5
	12 C	4	9				5	4		5	5	5	4.5
	12 E						6						
Fir tar	14						6						
Sulphite liquor	16		12				10						
Cornstarch	21	0.5	1	1			1						0.75
Potato starch	22	.5	1	1			1						.75
Producer-gas tar pitch	24 C				4								
Producer-gas tar	24 D	4											
Coal-tar pitches	28 A	6					7						7
	28 B	8	16		12	8							
	28 C	6.5											
	28 D	6.5			8								
	28 E				7								
	28 F				8								
	28 G				6								
	28 H				6								
	28 I	14		20			16	14		16	16	16	15
	28 J			16			12	10		12	12	11	11
Maltha	32				3								
Petroleum residuums	37 A	3	6				4						4
	37 C	3.5					4						4
	37 D				6								
	37 E				7								
	37 F				6								
Water-gas tar pitch	39	4.5	8		6.5		6	5	6	6.5	6.5	6	5
Wax tailings	40	3					4						3
Acid sludge	41	12	14				14						14

[a] The following materials were found to be of no use as binders: Lime (2), slag cement (8), wood pulp (15), beet pulp (17), lime cake (18), and impsonite (30). Those found to be too liquid for use as binder were: Pine-wood tar (12 D), pine-wood creosote (12 F), hard-wood tar (13), illuminating-gas tar (25), by-product coke-oven tar (26), coal-tar creosote (27), crude oil (36), water-gas tar (38), asphalt tar (42), and Pintsch gas tar (43). Satisfactory briquets were not obtained from beet-sugar molasses (19) and cane-sugar molasses (20). Blast-furnace tar is not produced in the United States.

[b] Contained sufficient magnesia to make 4 per cent MgO

Results of tests in briquetting different coals, showing percentages of binder necessary to make a satisfactory briquet—Continued.

Designation of binder.		Field designation of coals and lignites briquetted.										
Material.	No.	Illinois.		Indian Territory. 6.	Iowa. 2.	Missouri. 3.	New Mexico.		North Dakota. 1.	Oklahoma.	West Virginia.	
		11 C (4).	14.				1.	2.			7.	9.
1	2	15	16	17	18	19	20	21	22	23	24	25
Clay	1	8						8				
Magnesia	3	5						5				
Rosin	10	6						6				
Pitch	11	3.5						3.5				
Wood-tar pitch	12 A	12						12				
Pine-wood tars	12 B	5	6					6	10			
	12 C	5	6									
Cornstarch	21	1					1	1		1.5		
Potato starch	22	1					1	1		1.5		
Producer-gas tar	24 D	6										
Coal-tar pitches	28 A	7										
	28 B			8	8	8	14	8	16	10	8	10
	28 I					16			24			
	28 J								18			
Gilsonite	31 A	4										
	31 B	6										
Refined asphalt	....	6										
	....	8										
Petroleum residuums	37 A	4						6				
	37 B	4										
	37 C	4										
Water-gas tar pitch	39	6	6.5									
Wax tailings	40	4										
Acid sludge	41	14										
Pittsburg flux	44	8										

GOVERNMENT PUBLICATIONS ON BRIQUETTING.

The following reports (except those to which a price is affixed) can be obtained by application to the Director of the Bureau of Mines, Washington, D. C. The priced publications can be obtained by sending the price, in cash, to the Superintendent of Documents, Government Printing Office, Washington, D. C.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

BULLETIN No. 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER No. 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. $1.50.

BULLETIN No. 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905. J. A. Holmes, in charge. 1906. 240 pp. 20 cents.

BULLETIN No. 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907. J. A. Holmes, in charge. 299 pp. 25 cents.

BULLETIN No. 385. Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907–8, by C. L. Wright. 1909. 41 pp., 9 pls.

PUBLICATIONS OF THE BUREAU OF MINES.

BULLETIN 14. Briquetting tests of lignite at Pittsburg, Pa., 1908–9, with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 61 pp. 11 pls.

BULLETIN 24. Binders for coal briquets. 56 pp. Reprint of United States Geological Survey Bulletin No. 343.

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Bulletin 25

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

JOSEPH A. HOLMES, Director

MINING CONDITIONS

UNDER THE

CITY OF SCRANTON, PA.

REPORT AND MAPS

BY

WILLIAM GRIFFITH AND ELI T. CONNER

WITH A PREFACE BY JOSEPH A. HOLMES AND A CHAPTER BY N. H. DARTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

CONTENTS.

ILLUSTRATIONS.

PREFACE.

By Joseph A. Holmes.

The perpetuation of the supply of anthracite coal in Pennsylvania is a national as well as a State problem. Any investigation that shows how larger percentages of this coal may be saved in mining, without excessive cost, and without dangerous subsidence of the overlying surface ground, has a national as well as a local interest.

Messrs. Conner and Griffith, who conducted the investigations described in this report largely for the city of Scranton, are consulting engineers for the Bureau of Mines for investigations similar to those they have already made in connection with their Scranton work; and this report is published by the bureau in response to numerous requests, because of the fact that the information it contains will prove useful in the general solution of similar problems in many of the country's coal fields.

A study of the accompanying maps will show that the city of Scranton is underlain by 11 separate beds of coal, varying in thickness from 2 to 24 feet. It is estimated that before mining operations were begun these beds of coal contained underneath the present city limits of Scranton 600,000,000 tons of coal. The 27 collieries operating within the city limits, working independently of each other, had excavated and removed, up to March, 1911, an aggregate of 198,000,000 cubic yards of coal and accompanying rock, or 3,000,000 cubic yards more than the total amount of material excavated and to be excavated by the United States in constructing the Panama Canal. This fact illustrates something of the magnitude of the problem that the city of Scranton, with the aid of these engineers and of a special commission or advisory board, has undertaken to solve. The excavation has included 177,000,000 tons of coal and 44,000,000 tons of rock and accompanying refuse. This leaves about 420,000,000 tons of coal still to be removed.

As a result of other investigations and of experience in adjacent anthracite mines, Messrs. Conner and Griffith and the advisory board of engineers have advised that, as far as may be necessary to prevent dangerous surface subsidence, the spaces remaining beneath the

city of Scranton from the excavation of the above-described material should be filled with sand and other materials by flushing or other processes. This operation is expensive, but it is believed to be not beyond the reach of what is practicable, nor in excess of the value of the coal that may be removed and the amount of damages that may result from the caving in of the surface if such a plan is not carried out.

No one realizes so fully as do the authors of this report the need of additional tests and other investigations before the data now presented by them can be fully accepted as sufficient for all purposes in the solution of the problem; and it is expected that at some early date a more extensive series of similar tests can be made by the Bureau of Mines under the supervision of Messrs. Conner and Griffith on a larger scale and under a greater variety of conditions.

The field examinations made for the Bureau of Mines by N. H. Darton, which are described briefly in a chapter of this bulletin and will be discussed at length in a bulletin to be published later, indicate the extent and distribution of the sands, gravels, and other materials in the Scranton-Wilkes-Barre district available for flushing purposes if further tests indicate their relative merits; and it is expected that the relative merits of these different materials will soon be tested under such conditions as will furnish the desired information.

MINING CONDITIONS UNDER THE CITY OF SCRANTON, PA.

By WILLIAM GRIFFITH AND ELI T. CONNER.

LETTER OF TRANSMITTAL.

To the honorable Mayor and Council of the City of Scranton, and to the Board of Control of the Scranton School District:

GENTLEMEN: In rendering to you the following report upon the mining conditions under the city of Scranton, with observations and recommendations for the amelioration of the same, we feel that an apology is due for the voluminous proportions of the document. We trust, however, that you will consider the magnitude of the subject, and the manifest necessity under the circumstances of sacrificing brevity for clearness.

We have considered all the phases of the question in hand as fully and thoroughly as possible, having not only exhausted all the sources of present information available to us, but having made many tests and experiments as to the strength of materials and the efficiency of roof-supporting devices, both those at present in use and those originated by us. We may, therefore, perhaps be pardoned for felicitating ourselves with the consciousness that the whole question has been investigated and is herein considered with all the completeness which our ability and limitations would permit.

We desire to express our appreciation of the pleasant and courteous manner in which all the mining companies, including managers, superintendents, and inside officials, and the officials of the Fritz engineering laboratory of Lehigh University, have assisted us during the progress of the investigation, for without this cordial cooperation this report could not have been submitted in its present completeness. Our acknowledgments are also due to and on account of the treatment accorded us by the officials of the city and board of control, by the press and the public, and to Mr. S. N. Callender, for the use of his copy of the city atlas. Also to the members of the advisory board, for the care and enthusiasm with which they have considered this report, and for their practical suggestions, which are incorporated herein.

Very respectfully,

WM. GRIFFITH,
ELI T. CONNER.

SCRANTON, PA., *March 20, 1911.*

SUMMARY.

We would summarize our findings as follows:

The report is accompanied by plates which present a full set of plans of the city of Scranton and the mine workings thereunder, and also cross sections showing the positions of the several beds of coal and the intervening strata. From these plates one can readily determine, at almost any given point, the depth of the coal below the surface, the thickness of the beds, and the thickness of the intervening strata, since all of the plans are drawn to scale. These plates should be carefully studied in connection with the report and tables. As provided for in our contract, these plans are based upon information obtained from the maps, records, and data loaned to us by the several mining corporations, the Pennsylvania geological survey of 1885, and from our own personal investigations and measurements.

It will be noted that the coal basin underlying the city is wide and comparatively shallow, so that the coal beds and the intervening strata are comparatively flat, by reason of which fact the artificial pillars that may be inserted are not at all liable to slip or move on account of the dip of the seams. The only part of the coal measures underlying this city where there is an excessive dip is along the West Mountain, where pitches as steep as 50° are found. There is only a small part of the surface underlain by such pitching seams that carries important improvements, namely, in the vicinity of No. 23 School and what is locally known as the "Notch."

After about 40 days of careful inspection of underground conditions at all of the collieries operating within the city limits, we find that the total quantity of coal and refuse that has been extracted under the city of Scranton is about 221,000,000 tons.

There has been produced for market from the 27 collieries, 177,000,000 tons of coal.

The space excavated under the city is about 198,000,000 cubic yards. The total estimated excavation by the United States for the Panama Canal is 195,323,000 cubic yards.

It must not be understood that the hole from which the above material has been taken is still open. It is, of course, impossible to say what percentage of the space excavated remains open, but we would express the belief that it does not exceed one-half of the original, due to the numerous squeezes and cave-ins that have occurred.

After spending more than 40 days' time studying maps, after testing various materials used and considered for roof support in the

mines, and after tabulating and considering the information gained by these investigations, the conclusions we have reached are as follows:

Although some other devices are locally useful, the only method that combines the necessary qualities of strength, ease of application, and reasonable cost is filling the underground openings by what is known as the "flushing" method, using for flushing culm, sand, crushed rock, and other fine material that can be washed into the mines with water. This method was originated in the anthracite region of Pennsylvania, and has been extensively adopted in European mines, where, at great expense, sand, loam, and crushed rock are flushed into the mines following the removal of the coal by the longwall method of mining.

The tables and estimates of cost contained in the body of the report give in detail the results of our investigations and conclusions.

We therefore offer as our only recommendation that the flushing method be adopted, under the plans and specifications contained in the body of the report and in plates 1 to 24. From the report the following general conclusions are drawn:

1. Speaking broadly, the surface of the city can be supported by the methods recommended, and at a cost not in any sense prohibitory when considered with relation to the value of the property and operations for which support is absolutely essential.

2. Although in our judgment there are points in the city, as indicated in the detailed report, where at the present time there is distinct and immediate danger to life and property, yet the total area immediately threatened constitutes but about 15 per cent of the entire area of the city, and the danger is mainly from workings in surface beds.

3. On the west side the beds of the middle series are thick and close together, and the pillars are not columnized, creating a dangerous situation where the workings have not been closed by previous caves. Particular areas thus threatened can not be definitely specified on account of the inaccessibility of much of the mined-over area. Detailed investigation should be made of the portions of the mines not already closed. Relatively, we do not believe that a large part of the territory mentioned is threatened on account of so much ground having been already closed by caves.

Special attention is called to the conditions under schools Nos. 13, 23, and 29. They should be attended to promptly.

The lower series of beds, namely, the three Dunmores, are so thin and so far below the surface that with the usual system of mining we do not think they constitute a serious menace to the improvements on the surface, except along the margin of solid blocks of unmined coal and near the outcrops. In the deep-lying parts of the Dunmore beds we believe these solid blocks should be mined.

4. It would seem, therefore, to be not only the part of wisdom, but absolutely obligatory, to immediately commence supporting the points menaced, and thereupon proceed upon a general policy of giving support to the entire area of the city, for it must be borne in mind that with the mining activities that are constantly going on other and additional points of danger are not only liable to, but in all probability will, develop with each passing year—it might almost be said with each passing month.

5. Where the owner of the surface has undoubted right to the support thereof by coal pillars, in our opinion he could permit the removal of such pillars; the value thereof would under average conditions pay for such artificial support as we have recommended, if it be assumed that the pillars were mined and the support constructed by the same operating company. This observation, however, is based upon the assumption that in such case the operating company is one of the large transportation companies, inasmuch as although there might not be a profit in the immediate transaction of mining the pillars and installing the support, there would, of course, be a profit to such companies in carrying the coal to market.

6. Culm flushing should be used only in coal beds having light cover, up to 200 to 500 feet, according to the settlement expected. But sand, being four or five times as strong as culm, is better, and, being suitable for filling all beds under Scranton, is to be preferred.

7. We believe that the conclusions adduced from the tests made, and the calculations and tabulations based thereon, are reasonably reliable; yet we desire to record the opinion that there are conditions existing in the mines to which they might not apply. Such might be the case, for instance, in localities where several beds of coal are separated by thin strata of shale and slate or even sandstone, and the pillars in the two or more beds are not over one another, and it is proposed to reclaim all or any part of the pillars.

Even though an application of the above-mentioned tables might appear to fit the conditions, we believe that the only permissible procedure would be to first fill with flushed material all of the openings in the lowest bed of the series, and then fill upward until all the beds are filled, care being taken to have the flushed areas over one another. After all of the openings in all of the beds have been filled the pillars in the uppermost bed may be attacked, and the space occupied by each pillar filled as soon as the pillar is removed. No pillar reclamation should be permitted in any of the other beds until all of the pillars in the upper bed have been removed and the overburden has come to rest on the flushed material; after which the pillars in the next lower seam may be attacked and handled in like manner.

8. Harmonious plans and procedure between the coal companies, the city, the school authorities, and the public are essential to the

successful carrying out of any relief measures that are herein or may be hereafter suggested. Some facts that should be evident to all are that the prosperity of the city and of the community is to a large extent dependent upon the coal companies; that drastic laws or regulations that may curtail the mining of coal will necessarily react on the prosperity of the community; and that any ameliorating plans or compromises which it may be possible to effect between the city and the mining companies tend to prolong the life of the mining industry in Scranton and vicinity, and should be promoted.

It should therefore be the aim of all interested in mine-cave protective measures and of the companies operating the mines to adopt plans that will best conserve the welfare of all interested.

The expenditure for the work would of course be distributed over many years, the relief measures being applied at the points most in need of protection and as rapidly as proper arrangements could be effected and the necessary details, surveys, etc., prepared.

For the businesslike carrying out of the plans suggested it is recommended that a protective commission be established, consisting of not less than three nor more than five men, representing the city authorities, the school board, and the coal companies—this commission to have full and complete authority for the execution of the plans, and to be approved by the proper legal action. The commission should employ an engineer who should devote all his time to the service as active manager of the work.

THE REASON WHY.

The occasional mine caves or settlements in various parts of Scranton during the past years had long caused more or less public concern, until finally popular sentiment was brought to a focus by the settlement in Hyde Park, on August 29, 1909. This subsidence seriously damaged public school No. 16 and much other surrounding property; and, if it had occurred while school was in session, might have been the cause of loss of life.

Immediately following this event committees of councils, board of control, and board of trade took action in an endeavor to discover the immediate physical causes of the caving, as well as the legal responsibility therefor; and after much consideration, the former mayor, Hon. J. B. Dimmick, who was called in consultation with the joint committee, proposed the plan as set forth below and quoted from his final report, to wit:

To the joint committee of mine caves of select and common councils and of the board of control, Benton T. Jayne, chairman:

GENTLEMEN: I beg leave to herewith make report of what I have been able to accomplish in pursuance of your instructions looking to the selection of an engineer to be employed by the city and the board of control for the purpose of making a study of

the physical aspect of the entire mine-cave problem as it affects our city, and to make a report thereon together with such recommendations as would seem fitting and practicable.

Shortly after I received your instructions I laid the entire situation before John Hays Hammond, the well-known engineer, and he at once not only became deeply interested in the problem but offered his aid and assistance without compensation, direct or indirect, being moved simply by a willingness to perform public service.

After much thought and conversation with the gentlemen whose names are hereinafter given, the following definite plan has been worked out and awaits but acceptance upon the part of the city government and the board of control.

PLAN.

An advisory board has been formed consisting of five well-known engineers, with power to add to their number, namely: John Hays Hammond, D. W. Brunton, R. A. F. Penrose, jr., Lewis B. Stillwell, and W. A. Lathrop, this board having all agreed to act without compensation.[a] After a careful investigation of the necessary qualifications of the engineers that would make the actual study upon the ground, they suggested the names of Eli. T. Conner, of Philadelphia, Pa., and William Griffith, of Scranton, Pa., Mr. Conner having had considerable experience in anthracite-mining operations, and Mr. Griffith being especially informed as to the geological formation of this section. These two engineers to be employed by the city and the board of control, and upon the filing of their report, the same to be carefully considered and passed upon by the advisory board.

In order that the matter might be in complete form for your consideration, I secured from the two engineers, as recommended, a definite proposition, which is herewith incorporated in extenso:

SCRANTON, PA., *May 25, 1910.*

Hon. J. BENJ. DIMMICK, *Scranton, Pa.:*

As a result of our conference with you yesterday, in accordance with your request made at that time, we respectfully submit the following:

Of course, it is recognized by everybody that the situation is serious regarding the mining conditions under portions of the city of Scranton, and the proposition of proecting the whole city can best be met by a frank recognition of the varying conditions that undoubtedly exist, certain sections of the city being really in danger, while others are, practically speaking, not menaced. While our proposed report would be general in character, and intended to cover the entire city, yet it would properly be especially concerned with those sections of the city that are immediately threatened.

It seems to us that what is most necessary at the present time is more accurate knowledge of the physical conditions which now prevail, and we would suggest a report based upon the results of a careful study of such physical conditions as they at present exist in the mines under the city of Scranton; this report to be general in its nature. We would group together the various similar conditions in several classes, to each of which similar remedies or lack of remedy might apply, with suggestions not only as to remedies but also as to the approximate cost thereof under certain ascertained conditions. We should expect to also include in said report such general observations and recommendations touching the entire situation as would seem to be justified by our inspection and study thereof. The completeness and value of any such report would depend in a large measure upon the assistance and cooperation tendered us by the several mining companies who are now operating under the city and of the city and school authorities.

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[a] The advisory board subsequently included the following additional members: Dr. H. S. Drinker, president of Lehigh University; Dr. J. A. Holmes, director of the Bureau of Mines; Prof. J. F. Kemp, Columbia University; Prof. J. F. McClelland, Yale University; and Prof. H. L. Smyth, Harvard University.

It is to be distinctly understood that such proposed report and study of the situation existing under Scranton would be based upon such information as might be obtained from the second geological survey and from such other maps of the various coal-mining companies and the city and school authorities, to which access could be obtained for the engineers, and from such personal inspection of accessible portions of the mines as, in our judgment, shall be necessary. We would, however, give expression to our belief that such surveys are sufficiently accurate and reliable as a basis for the general conclusions that the report will be expected to set forth.

It seems to us that the information to be secured through such a report would be the first requisite to a subsequent detailed investigation and application of any remedies which might be suggested for the amelioration of the mining conditions under this city.

Yours, respectfully,

(Signed) WM. GRIFFITH,
ELI. T. CONNER,
Mining Engineers.

It therefore remains but for the community, through its city government and the board of control, to employ these two engineers at the price stipulated in order to receive a general report upon the cave problem that should command the respect and the confidence of all parties interested, not only because it will have been prepared by engineers selected by a board composed of experts of national reputation, but also because the very findings of such engineers would, in their turn, be submitted to and reported upon by that same advisory board. In short, the community would then be provided with information as to facts and opinions as to remedies that would form solid ground for both future deliberations and future activities.

I can not refrain from suggesting, assuming the acceptance of this most unselfish offer upon the part of men of high professional equipment and without personal interest in the welfare of Scranton, that, simultaneously with the enactment of the necessary legislation to carry into effect this plan, there should be official appreciation of their proffered assistance.

Respectfully submitted.

J. BENJ. DIMMICK.

Certified copy.

EVAN R. MORRIS, *City Clerk.*

SEPTEMBER 15, 1910.

GEOLOGY.

The city of Scranton occupies the surface overlying the whole width (5 miles) of the Lackawanna coal field, and extends about 5 miles up and down the valley. The central part of the city is over the center of the coal basin, while the margin of the basin on the East and West Mountains nearly coincides with the city line along those hills.

The floor of this coal basin is formed by the hard Pottsville conglomerate or "pudding stone," which comes to the surface on the mountain sides east of Roaring Brook, and dipping down under the surface in the form of a deep trough or basin passes under the central part of the city at a depth of several hundred feet, and again reaches the surface on the flanks of the West Mountain. Passengers on the Laurel Line can note this conglomerate on both sides of the Roaring Brook ravine and at the stone quarry on the east near the switch where the Dunmore branch leaves the main line.

It is the conglomerate that forms the roof of the Lackawanna tunnel at Nay Aug, and is again cut by this railroad on the west side of the valley, at Leggetts Creek Gap.

As before stated, this rock forms the floor of the coal basin. No coal exists below it; therefore all the coal under the city of Scranton is to be found in the rocks which fill this trough or basin and overlie the Pottsville conglomerate. The coal is deposited in parallel layers or beds, known locally as "coal veins," that are approximately parallel to the conglomerate floor, and lie deepest in the central part of the basin. They extend with persistence and considerable regularity from outcrop to outcrop, except where they were removed with other rocks during the surface erosion of past ages.

In all, there are 11 principal coal beds under this city, known by names as follows, beginning with the highest:

The Eight-Foot coal bed, which is present only in two small areas or islands under the highest part of the Hyde Park hill.

The Five-Foot and Four-Foot beds, which are only in the hill top on the west side from Dodge to Marvine, above the level of the Lackawanna River.

The Diamond and Rock beds, which are on the west side only of Lackawanna River, under Bellevue, Hyde Park, Providence, and parts of Keyser Valley.

The Big or Fourteen-Foot and New County beds, which extend under the whole west side, and also become surface beds on the east side at the National colliery, near the south line of the city; also under the central city and hill section, nearly to the Moses Taylor Hospital.

The Clark, Dunmore No. 1, Dunmore No. 2, and Dunmore No. 3 beds, which extend under the whole city from Nay Aug Park to the West Mountain.

For the thicknesses of these several beds, the distances between them, and their relative positions in the coal measures, the reader is referred to the columnar section sheets contained in Plates 1 to 24 of this report.

HISTORY.

EARLY DEVELOPMENTS.

The late Dr. B. H. Throop reported to an industrial convention at Tunkhannock, in the year 1842, that the Lackawanna Valley from Archbald to Pittston "contains upward of one hundred coal mines opened, and many of them are made at present a source of profit both from domestic and foreign markets. There are sent some five or six thousand tons of coal annually by sledges and wagons to the States of New York and New Jersey, in exchange for salt, plaster, etc."

In 1841 the first furnace of the Lackawanna Iron & Coal Co. was filled and fired, and though this effort to manufacture iron from local ores proved a total failure, it nevertheless gave a decided impetus to the coal-mining industry of this locality. Subsequently iron ore and limestone were brought from a distance, and anthracite was successfully used for smelting iron. Since this beginning the coal industry of Scranton has continuously flourished until the present.

The mines worked by the iron company in 1841 were on both sides of Roaring Brook. The Clark bed was worked near the viaduct; later the Dunmore beds were worked near the site of the present Laurel Line power house by what were known as the Rolling Mill drifts. For several years these were the principal mines in Scranton.

In 1851 the Lackawanna & Western Railroad was built from Scranton to connect with the Erie road at Great Bend. The Delaware & Cobbs Gap road (chartered in 1849) was merged with the Lackawanna, and in 1856, under the name of the Delaware, Lackawanna & Western Railroad, was built through from Scranton to the Delaware River. In 1858 the Lackawanna & Bloomsburg road was built. Equipped thus with new and permanent outlets for its resources, the mining industry of the valley and the city advanced with rapid strides.

About 1852 the Diamond mines were opened. In 1854 the Rockwell mine at Leggetts Gap, and the Bellevue colliery were opened. The opening of numerous other coal operations followed in rapid succession.

MINING METHODS.

The room and pillar system of mining was adopted in these old mines, and has been continued in all the mining of the region to the present time. This method consists, briefly, in driving an airway and a gangway about 15 feet apart and parallel in the coal bed. On the high side—that is, to the rise—chambers or rooms are driven parallel to each other and at right angles to the gangways. The rooms are about 30 feet wide and are separated by partitions about 15 feet in thickness called pillars. The coal production of the mine is mainly taken from the contents of the rooms; the pillars, which comprise approximately one-third of the coal, are left to support the surface. This practice of leaving one-third of the coal for surface support was adopted at the start, and was found sufficient for the comparatively light overburden to be sustained in the mining of the beds near the surface. It has been continued as an empirical rule with little variation, in the deeper mining under the city, without reference to the weight on the pillars or the strength of the coal.

In the past the several beds of each mine were worked independently of each other and no attempt was made to regulate the size,

position, and distribution of pillars aside from the one-third rule. Consequently, the pillars are not columnized; in other words, they are not exactly over each other. Many of the thick beds of the middle measures under the Hyde Park and Providence sections are close together. Therefore the pillars in these thick beds, not being columnized, have a decided tendency to crush through the interval between the beds, the pillars of an upper bed settling into the excavations or rooms of the lower workings.

Another feature that should be brought out in this historical sketch of early mining in Scranton is that the universal practice in the old days was to mine only the best, thickest, and most accessible coal beds, and also only the profitable parts of each bed, and to leave unmined, as refuse, the parts which for one cause or another were found more expensive to work. Therefore, in these latter days some of the coal beds already mined over and ready to be abandoned have been found to carry rider coal above or bottom coal below, which can be removed at a profit. And, therefore, for the past few years the total production from several beds has been from such remining of top and bottom coal. This remining, of course, leaves the pillars from 2 to 6 feet taller than they were before for the same horizontal area, consequently the pillars are much weaker and less able to support the overburden.

In consequence of the several conditions related above there have been from time to time numerous and more or less serious caves or subsidences of the surface, principally on the west side, which have caused some damage to surface property, but no loss of life. In every instance the damage has been speedily repaired and temporarily forgotten. The accumulated result of these repeated subsidences has probably left certain parts of the surface in that section of the city in more stable condition than they were before. This phase of the subject, however, will be considered in a subsequent chapter.

STATISTICS OF COAL PRODUCTION.

The following statistics of the coal-mining industry in Scranton are based upon the result of the surface and underground investigations made by us, and from our inspection of the mine maps, taken in conjunction with the annual production of coal as shown in the published statistics contained in the reports of the State mine inspectors.

TABLE 1.—*Total production of coal mined under the city of Scranton, 1841–1910.*

Year.	Production.	Year.	Production.
	t.		*tons.*
1841–1872	00	1892	21,894
1872	47	1893	22,640
1873	81	1894	14,488
1874	58	1895	42,677
1875	60	1896	83,848
1876	83	1897	15,907
1877	67	1898	27,826
1878	32	1899	08,338
1879	29	1900	81,573
1880	85	1901	41,215
1881	61	1902	45,310
1882	95	1903	78,771
1883	01	1904	02,694
1884	91	1905	57,380
1885	88	1906	53,190
1886	69	1907	48,258
1887	09	1908	86,728
1888	19	1909	15,774
1889	27	1910	00,000
1890	73		
1891	11		176,839,619

TABLE 2.—*Statistical table of coal mining.*

Coal beds.	Average thickness of beds.	Original area before mining.	Area mined over.	Area to be mined.	Approximate area of pillars.	Area of mine excavation.	Foot-acres mined over, including pillars.	Foot-acres excavated, excluding pillars.	Foot-acres to be excavated, leaving one-third for pillars.
	Feet.	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*			
Eight-foot	7.6	140	111	29	35	76	848	577	146
Five-foot	4.4	2,000	1,093	907	364	729	4,809	3,208	2,660
Four-foot	3.6	2,400	994	1,406	331	663	3,578	2,387	3,518
Diamond	9.4	4,160	3,562	598	1,187	2,375	33,495	22,325	3,746
Rock	5.2	4,500	3,000	1,500	1,000	2,000	15,600	10,400	5,200
Big	12.2	6,000	4,831	1,169	1,610	3,221	58,938	39,296	9,508
New County	6.0	5,360	1,549	3,811	516	1,033	9,294	6,198	15,244
Clark	6.7	7,860	6,040	1,820	2,013	4,027	40,468	26,981	8,130
Dunmore No. 1	3.0	7,500	690	6,810	230	460	2,070	1,380	13,620
Dunmore No. 2	4.0	9,630	2,533	7,097	844	1,689	10,132	6,756	14,194
Dunmore No. 3	3.3	8,500	1,573	6,927	524	1,049	5,191	3,462	15,240
	....	58,110	25,976	32,134	8,654	17,322	184,418	122,970	91,206

Total space excavated in the mines under Scranton ....cubic yards..	198,104,670
Total estimated excavation for Panama Canal ....do....	174,666,594
Total approximate tonnage of coal produced to January 1, 1911 ....long tons..	176,840,000
Total approximate tonnage of coal waste and mine refuse excavated, but not included in production ....long tons..	44,500,000
Average production per foot-acre excavated ....do....	1,440
Average production per foot-acre mined over ....do....	960
Number of collieries and mines operating under the city	27

PRESENT MINING CONDITIONS UNDER SCRANTON.

The following tabulated notes give in condensed form the actual conditions of the mining under the city and school properties at present, as found by your engineers during an extended underground inspection that lasted about 40 days.

In connection with these notes the plates accompanying this report should be well studied. These plates set forth in a more intelligible form than can possibly be shown by words the location and extent of the mining in all the coal beds under the city, and by plans, cross sections, columnar sections, etc., clearly indicate the geology and distribution of the beds throughout the measures.

Scranton Coal Co. collieries.

PINE BROOK COLLIERY.

(Works central city section from the river to Nay Aug and from Poplar Street to Beach Street.)

Coal beds.	General conditions.
Eight-foot......	
Five-foot.......	
Four-foot.......	
Diamond.......	
Rock...........	
Big.............	Depth, 30 to 80 feet (see sections on Pls. 5); thickness, 12 to 16 feet; pillars sound ved; local falls; old workings mainly fallen ible.
New County....	k.
Clark...........	
Dunmore No. 1.	et thick: some places increased taken up for height; chambers general conditions good; depth, s on Pls. 1, 2, 3, 4, and 5).

Scranton Coal Co. collieries—Continued.

PINE BROOK COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Dunmore No. 2	No. 4	filled with gob rock; no dis-	352 acres
	No. 26		
	No. 9	Inaccessible on account of water. (See Stevenson and Knight report.)	
	No. 35	Pillars sound; conditions good. Now working.	
	Technical High	Roof is hambers	
	No. 33	Pillars	
	Central High	Partly not yet	
	No. 3	Now bottom rock; coal pil- with gob; conditions	
	No. 2	Old nall; rooms large; local	
Dunmore No. 3	No. 36		354 acres mined. Bed 2½ to 5 feet thick, including 10 to 18 inches refuse; all chambers nearly filled with gob, except roadway in center; pillars strong and conditions generally good; depth, 300 to 250 feet (see sections on Pls. 1 to 24).
	Central High		
	No. 33		
	Technical High		
	No. 9		
	No. 4		

MOUNT PLEASANT COLLIERY.

(Works Hyde Park, from Lackawanna River to Keyser Creek, and between Lafayette and Pettibone Streets.)

Eight-foot	No. 18	School over outcrop of bed; bed not mined	33 acres n ... itcrop to 80 feet over center of ... 17); thickness, 8 feet 8 inches ... refuse; all mined over, except ... abandoned; pillars standing in
Five-foot	do	Depth, 124 feet; openings filled with gob and falling fire clay; pillars reported standing firm, reinforced by this falling strata shaken by old squeeze in lower beds; present conditions fair	122 acres ... t (see sections on ... hes; includes 10 ... feet 5 inches of ... l with falling fire
Four-foot	do	Depth, 164 feet; pillars large and firm; rooms filled with rock	120 acres ... , 16, and 17; twin ... rock, 6 to 7 feet; ... filled with rock;
Diamond	do	Mined, closed, abandoned, and inaccessible; depth, 280 feet	188 acres ... 14, 16, and 17; thick- ... workings formerly ... and inaccessible.
Rock	do	Mine abandoned and inaccessible account falls and old squeeze; depth, 315 feet.	190 acres mined. D ... 16, and 17; thick- ness, 7 to ... reported pillars more tha ... , and inaccessible on accoun...
Big	do	Depth, 378 feet; workings inaccessible on account of roof falls, but pillars reported large and not crushed. (See maps.)	214 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 14 feet 9 inches; 1 foot 7 inches refuse; workings partly open, but mainly closed by local falls and old squeeze. a
New County	do	Partly mined; rooms filled with rock; remaining coal soon to be mined, leaving usual pillars; depth, 418 feet.	208 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 9 feet 8 inches, includes 1 foot 10 inches of refuse; open and accessible; rooms partly filled with gob; pillars sound, usual size; conditions good. a
Clark	do	Substantial pillars; some chipping; no indication of settlement; depth, 481 feet.	202 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 6 feet 5 inches, includes 8 inches of refuse; rooms wide; pillars slightly air chipped, but otherwise sound; conditions fair.
Dunmore No. 1	do	Depth, 598 feet; only partly mined, by two gangways; no chambers.	22 acres mined. Depth, see sections on Plates 14, 16, and 17; thickness, 1 foot 4 inches to 1 foot 8 inches; vein too thin for profitable mining and now abandoned; openings filled with gob; conditions good.

a Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick beds lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Scranton Coal Co. collieries—Continued.

MOUNT PLEASANT COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Dunmore No. 2	No. 18	Depth, 612 feet; large pillars, sound and undisturbed; rooms nearly full of gob.	92 acres mined. [illegible] ness, 4 [illegible] good; a [illegible] at present.
Dunmore No. 3	do	Pillars sound, of usual size; chambers partly filled; depth, 704 feet	115 acres mined. D[illegible]n Plates 14, 16, and 17; thickness, 4 fe[illegible]s 1 inch slate and bone top; rooms ne[illegible] floor raised for height.

CAPOUSE COLLIERY.

(Works Keyser Valley from Keyser Creek to outcrop and from Jackson Street 1 mile northeastward.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot		do	Do.
Four-foot		do	Few surface improvements.
Diamond	No. 17	Depth, 92 feet; inaccessible under school on account of removal of surrounding pillars, but under school for area of 200 feet square pillars reported sound and still standing.	262 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 10 feet; workings have been remined, and pillars removed over a large area; mining in Diamond bed has ceased.
Rock	do	Depth, 136 feet; inaccessible for reason stated above; similar conditions prevail; nearest accessible point 400 feet from school.	193 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 3 feet 10 inches; rooms two-thirds filled with gob; partly remined and inaccessible.
Big	do	Depth, 216 feet; pillars as shown on maps; sound, except slight chipping; local falls in rooms under school.	317 acres mine[illegible] 14; thickness, [illegible] no r[illegible] local falls; [illegible]e.
New County	do	Depth, 246 feet; rooms two-thirds filled with gob; also local falls; pillars good; no indication of settlement.	100 acres [illegible]
Clark	do	Depth, 311 feet; water under school prevented approach nearer than 150 feet; pillars sound, except some chipping; rooms wide; pillars usual size, well distributed; conditions fair.	412 acres mined. Depth, see sections on Plates 12, 13, and 14; thickness, 8 feet, includes 11 inches refuse; many local falls, but no squeeze or other settlement; good roof; fair conditions at present; no remining except at outcrop.

Dunmore No. 1	do	Depth, 360 feet; not mined	This vein not mined as yet; too thin. Depth, see sections on Plates 12, 13, and 14.
Dunmore No. 2	do	Depth, 380 feet; pillars sound, usual size; rooms nearly filled with gob; conditions good.	139 acres and 14; thick- bottom raised except road-
Dunmore No. 3	do	Depth, 480 feet; not mined	55 acres mined. This vein not being mined; too thin for profitable mining at present.

WEST RIDGE COLLIERY.

(Works Providence section, North Main Avenue to outcrop between Putnam and Clearview Streets.)

Eight-foot		Eroded	Eroded.
Five-foot	No. 40	Depth, 66 feet, workings inaccessible; approached to point about 300 feet from school; workings filled with falling fire-clay roof; workings now controlled by Clearview Coal Co.	84 acres mined. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 4 feet clear; roof falling; 3½ to 4 feet of fire clay and ll the chambers; . next vein below.
Top split of Four-foot.	do	Depth, 88 feet (see Clearview Coal Co., p. 43)	9 acres ections on Plates 2, 7, s; 3 to 4 feet of rock filled with rock and . Five-foot beds.
Four-foot	do	Depth, 116 feet. Reported formerly worked by West Ridge, but this part now controlled by Clearview Coal Co. (see p. 43).	90 acres mined. Depth, see sections on Plates 2, 7, 11, and 13; thickness, 3 feet clear coal; falling rock roof; workings filled with falling roof and rock from top split.
Diamond, Rock, Big, New County, Clark.	do	These beds worked by Von Storch colliery and Delaware & Hudson Co. (see p. 35).	See page 35.
Dunmore No. 1	do	Depth, 564 feet; extensions of working here since Stevenson and Knight report; pillars sound and chambers well filled, except roadways.	36 acres mined. Depth, see sections on Plates 2, 7, 11, and 13, thickness, 3 feet 1 inch, 4 inches of refuse; 3 feet of bottom raised for height; rooms filled with gob, except roads; pillars sound; conditions apparently good.
Dunmore No. 2	do	Depth, 616 feet; workings now extended under this school; pillars sound and usual size; rooms filled with gob, except roadway; conditions good.	43 acres mined. , 11, and 13; thickness, 2 ; 4 feet of bottom taken adway in center, filled
Dunmore No. 3	do	Depth, 686 feet; mined under school, but inaccessible on account of gas and water; conditions reported unchanged since Stevenson and Knight report.	99 acres m

Scranton Coal Co. collieries—Continued.

RICHMOND NO. 3 COLLIERY—BRYDEN SHAFT.

(Works center of valley. Area bounded by river, Olyphant Road, and Manville farm and narrow strip extending to East Market Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot	No. 30	Eroded	Eroded.
Five-foot	do	do	Do.
Four-foot	do	do	Do.
Diamond	do	do	Do.
Rock	do	Depth, 138 feet; not mined	Not mined; depth, 109 feet under river flats; much sand and gravel, with thin rock cover over bed; too dangerous to mine.
Big	do	Depth, 200 feet; pillars large and firm; present conditions good	88 acres [illegible] rock.
New County	do	Not mined	Depth, see sections on Plate 9; not mined; too thin or dirty to be profitably mined at present.
Clark	do	Depth, 366 feet; pillars usual size and sound except air chipping; roof good; no indication of settlement.	96 acres [illegible] thickness, 5 feet 9 [illegible] look fair, but all
Dunmore No. 1	do	Thin and unworkable at present	Thin and [illegible] his bed is split; [illegible] No. 1 and the
Dunmore No. 2	do	Depth, 520 feet; pillars sound and as shown on maps; rooms walled with gob on both sides of road; conditions good.	76 acres [illegible] 9; thickness, 4 feet 6 [illegible] ½ feet of bottom rock [illegible] nearly full of gob, [illegible] known as the No. 3 [illegible] at Dickson.
Dunmore No. 3	do	Depth, 544 feet; pillars usual size, sound and firm; rooms well filled with gob, except roadway in center; conditions good.	86 acres mined. Depth, see sections on Plate 9; thickness, 4 feet 3 inches, includes 1 foot 1 inch refuse on top; 1½ feet of bottom raised for height; rooms, except roadway, filled with gob. At Dickson and Manville this bed is known as the No. 4, or China bed.

Delaware, Lackawanna & Western Coal Co. collieries.

NATIONAL COLLIERY.

(Works South Scranton section, from Beach Street to city line, and from river to outcrop.)

Coal beds.					General conditions.
Eight-foot......					
Five-foot.......					
Four-foot.......					
Diamond.......					
Rock..........					
Big and N County.					Plate 20; thickness of Big anty, 5 feet; close together mined and caved; now re-
Clark..........					
Dunmore No. 1.					to mine.
Dunmore No. 2.....	No. 7..............	Depth,	'school; too dangerous weak, partly crushed;	752 acres	
	No. 11..............	Depth,	but sound; openings	These ar	
	No. 10..............	Depth,	arge; gob piers built		
	No. 8	Depth,	ccount of being filled		
	No. 15..............	Depth	school yard, through gs large; 12 sandstone litions at present good.		
Dunmore No. 3.....	....	Thin, and not mined.........		This bed very thin; not mined.	

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

DODGE COLLIERY.

(Workings mainly in Taylor Borough. Now opening upper veins in Twenty-second ward of city.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot	No. 43	Eroded	Mainly eroded; may perhaps be present under very small area under highest land.
Five-foot	do	Depth, about 25 feet; not yet mined; preparations to mine now in progress.	Not yet mined; thickness, 2 to 3 feet.
Top split of four-foot	do	Depth, 49 feet; not yet mined; new workings now about 150 feet from the school; chambers will soon extend under school.	Mines now being opened; depth, see sections on plate 18; thickness, 2½ feet; 4½ feet of bottom raised for height.
Underlying veins	do	All underlying beds worked from Bellevue colliery (see p. 27)	Dodge colliery does not operate lower beds under this city.

HAMPTON COLLIERY.

(Works Diamond and Rock veins only. Hyde Park and Keyser Valley, west of South Main and south of Luzerne Streets.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot, four-foot	No. 32 Annex	See Hyde Park colliery, page 29	Not mined as yet (see Hyde Park colliery, p. 29).
Diamond	do	Depth, [illegible] r a long time, but now reported sound, being [illegible]emining.	561 acres mined. Depth, see sections on Plates 14 to 16; thickness, about 10 to 12 feet; top bench, 6 to 8 feet, formerly mined, now remining for bottom bench, and reinforcing pillars with gob walls; much of mined area long closed by old squeeze.
	No. 21	Depth, [illegible]	
	No. 19	Depth, [illegible]	
Rock	No. 22 Annex	Reported inaccessible on account of caves; maps show fair pillar support.	370 acres mined. Depth, see sections on Plates 14 to 16; thickness, 9½ feet, includes 3 feet of refuse; long worked and mostly abandoned; bed squeezed and closed in places; now reclaiming pillars under Keyser Valley.
	No. 19	Depth, 325 feet; caved and inaccessible.	
	No. 31	Depth, 286 feet; caved and inaccessible.	
Big and other lower beds.	No. 22 Annex	Mined at Central and Hyde Park collieries (see pp. 28, 29)	These beds mined by Central and Hyde Park collieries (see pp. 28, 29).

BELLEVUE COLLIERY.

(Works Hyde Park and Bellevue sections from river to South Main Avenue, between Dodge and Oxford mines.)

Eight-foot		Eroded	Eroded.
Five-foot, four-foot		See Dodge colliery, page 26	See Dodge colliery, page 26.
Diamond	No. 12	Depth ... st two-thirds of building workings; large openings or bottom coal; should be	234 acres
	No. 13	Depth, 230 feet; inaccessible because crushed	
	No. 29	Eroded	
	No. 32	Depth, 185 feet; on roll; solid under school; conditions good at present.	
	No. 43	Depth, 221 feet; pillars small but sound; now remining for bottom coal and stowing rock and reinforcing pillars with gob walls.	
Rock	No. 13	Depth, 282 feet; approached to about 100 feet from this school; inaccessible farther on account of squeeze.	371 ... , 8 feet ... d and ... have ... vein,
	Nos. 12, 29, 32, 43	Inaccessible on account of old crush	
Big	No. 12	Depth	367 acres ... nd 17; thickness, ... r top or bottom ... emaining bench. ... ny parts of mine,
	No. 13	Depth	
	No. 29	Depth	
	No. 32	Depth	
	No. 43	Not ...	
New County	No. 12	... pillars	118 acres ...
	No. 13		
	No. 43	... er maps	
	Nos. 32 and 29	...	vein; columnization attempted in recent mining.

a Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick beds lie ... in the several beds are not columnized, thus permitting pillars of an upper bed to break through the strata into the chambers or openings of an ...

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

BELLEVUE COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark	No. 12	Depth, wall of	335 acres 1
	No. 13	Depth, and as	
	No. 20	Depth, stopped rooms,	
	No. 32	Depth, crest of	
	No. 43	Depth,	
Dunmore No. 1		Not mined	3 acres mined. Preparations now being made to work this bed.
Dunmore No. 2	No. 12	Depth, 350 feet; mined, condition good	84 acres mined. Depth, see sections on Plates 15 and 17; thickness 5 to 6 feet; pillars usual size, and strong; conditions good throughout.
	No. 43	Not mined	
	No. 13	Depth, about 510 feet; gangway under school; conditions good	
	No. 20	Depth, 320 feet; workings in good condition; pillars sound and usual size.	
	No. 32	Depth, 800 feet, conditions good	
Dunmore No. 3		Not mined	38 acres mined. Opening in preparation for working this bed.

CENTRAL COLLIERY.

(Works Hyde Park section, South Main Avenue and Keyser Valley, south of Washburn Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot		Part eroded	Partly eroded.
Four-foot		Part not mined	Balance not mined.
Diamond Rock		Worked from Hampton colliery (see page 26)	See page 26.
Big	No. 32 Annex	Reported caved and inaccessible	362 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 13 to 18 feet; 2 to 3 feet refuse; this vein is generally closed by numerous local falls; pillars doubtless crushed or shattered in some places.a
New County	do	Reported flushed and inaccessible	300 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 9 to 10 feet; 2 feet refuse.a

Clark	do	Pillars sound, as shown on map; some local falls	370 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness, 8 feet; 1 foot refuse.
Dunmore No. 1	do	Pillars sound; roof good; hard floor; recently mined; conditions good.	10 acres mined. Depth, see sections on Plates 14, 15, and 16; thickness 4 feet 11 inches coal and 3 feet 1 inch refuse; twin bed—perhaps represents Dunmore Nos. 1 and 2 united.
Dunmore Nos. 2 and 3.		Not mined	Not mined.

HYDE PARK COLLIERY AND CONTINENTAL COLLIERY.

(Work Keyser Valley and Hyde Park section to South Main Avenue, between Lafayette Street and Luzerne Street.)

Eight-foot		Eroded	Eroded.
Five-foot	No. 31	Depth, 104 feet; mine just being opened; gangway working toward school, but under school not yet mined; conditions good.	2 acres mined. Depth, see sections on Plates 14 and 16; thickness, 4 feet 8 inches clean coal. This bed extends under Hyde Park section generally, but until recently no mining has been done in it; now being developed from Hyde Park colliery.
	No. 19	Depth, about 140 feet; not yet mined	
Four-foot	No. 31	Depth, about 144 feet; mine just being opened; gangway extending quite close to, but not now under the school; conditions good.	10 acres mined. Depth, see sections on Plates 14 and 16; thickness, 2 feet 10 inches, including 1 inch refuse. This bed extends under the Hyde Park section generally, but until recently has not been mined; now being developed from Hyde Park colliery.
	No. 19	Depth, about 175 feet; not mined	
Diamond	No. 31	Mined from Hampton (see p. 26)	355 acres mined. (See p. 26.)
Rock		Mined from Hampton (see p. 26)	240 acres mined. (See p. 26.)
Big	No. 31 No. 19	Depth, 374 feet; worked and caved; inaccessible Depth, 405 feet; inaccessible; mined and caved	514 acres mined. Depth, see sections on Plates 14 and 16; thickness, 13 to 18 feet; long mined; caved over large area and workings now abandoned.[a]
New County	No. 31	Depth [illegible] no indications of settle-	431 acres [illegible] Plates 14 to 16; thick- [illegible] refuse; workings in this [illegible] le and pillars standing [illegible] ie; the caves or squeezes [illegible] rlying beds are not col-
	No. 19	Depth, [illegible] remainder part mined;	
	No. 14	Depth, [illegible] b because of squeeze in [illegible] angway to 50 feet from school lot, all quiet now.	

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

HYDE PARK COLLIERY AND CONTINENTAL COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark	No. 31	Depth, 483 feet; roof, ... pipe, under ... ush ... l.	360 acres ... thick- ... stand- ... of this ... al; this ... lls and
	No. 19	Depth, about 495 feet; ... cessible. ... ac-	
Dunmore Nos. 1 and 2.	No. 31	Depth, about 520 feet; now opening these beds; not now mined under school, but gangway is approaching; pillars, roof, and floor all good.	8 acres mined. Depth, see sections on Plates 14 and 16; thickness, No. 1 bed, 1½ to 2 feet; dividing rock, 8 feet; No. 2 bed, 3½ feet. Mining under this section in these beds was recently begun and is now developing.
	No. 19	Not mined	
Dunmore No. 3		Not mined in this section	Not mined in this section.

DIAMOND COLLIERY.

(Works North Hyde Park to Providence; river to Keyser Creek, between Pettebone Street and Court Street.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded under schools	54 acres ... ate 12; ... This ... Hill ... now ... subsidence.
Five-foot	No. 20	Depth, 51 feet; mined by Diamond drift	200 acres mined. Depth, see sections on Plate 12; thickness, 5 feet. This has been well mined over from Diamond drift; partly caved and abandoned.
	No. 41	Depth, 60 feet; mined, caved, and inaccessible under both schools	
Four-foot	No. 20	... ft workings and ... s fair; fair roof.	42 acres mined. Depth, see sections on Plate 12; thickness, Twin bed 7 to 8 feet, including dividing rock 2½ feet thick; this bed nearly closed, result of Diamond squeeze.
	No. 41	... now closed and ... 50 feet of school.	
Diamond	No. 20	Depth, 255 feet; mined, closed, and inaccessible	630 acres mined. Depth, see sections on Plate 12; thickness, 8 to 12 feet; mined from Diamond shaft; closed by falling roof and general squeeze; [a] now inaccessible.
	No. 21	Eroded	
	No. 41	Depth, 242 feet; closed, caved, and inaccessible.	
Rock	No. 20	Depth, 284 feet	480 acres mined. Depth, see sections on Plate 12; thickness, 8 feet; mined from Diamond shaft; closed by general squeeze; now mining top split in Tripp shaft; hindered by 8 to 15 feet rock. [a]
	No. 41	Depth, 272 feet; caved and inaccessible under both schools	
	No. 21	On outcrop; not mined; too close to surface	

Big	No. 21	Depth, 107 feet; map shows large pillar under school, but mine workings caved and inaccessible.	490 acres mined. Depth, see sections on Plate 12; thickness, 10 to 13 feet; mined from Diamond shaft; closed by general squeeze.[a]
	No. 20	Depth, 345 feet; caved and inaccessible	
	No. 41	Depth, 331 feet; caved and inaccessible	
New County	No. 20	Depth, 400 feet; not mined; nearest work 450 feet distant.	131 acres
	No. 2	Depth, 160 feet; not mined.	
	No. 41	Depth, 368 feet; we reached point in workings near school; chambers now being worked toward school; rooms, 26 feet; gob walls both sides.	use.[a]
Clark	No. 20	Depth, 462 feet.	615 acres mined. Depth, see sections on Plate 12; thickness, 7½ feet, includes 8 inches refuse; largely mined over; disturbed by the general squeeze, and now full of water.
	No. 41	Depth, 440 feet; inaccessible under both schools, on account squeezed area and water.	
	No. 21	See Manville colliery, page 32.	
Dunmore Nos. 1, 2, and 3.		These seams not now mined under any school building.	21 acres mined. Depth, see sections on Plate 12. These beds are 2 to 5 feet thick and are only being mined from Tripp shaft, but workings are of small extent.

BRISBIN COLLIERY.

(Works under Keyser Valley and Hill section, between Hyde Park and Providence.)

Eight-foot		No schools over Brisbin workings.	24 acres mined. Depth, see sections on Plate 7, thickness, 8 feet 10 inches; mined out and robbed.
Five-foot		do	130 acres mined. Depth, see sections on Plate 7; thickness, 8 feet 10 inches.
Four-foot		do	123 acres mined. Depth, see sections on Plate 7; thickness 3 feet.
Diamond		do	Worked from Diamond colliery. (See p. 30.)
Rock		do	182 acres mined. Depth, see sections on Plate 7; thickness, 3 feet 11 inches; mined out and caved.
Big		do	289 acres mined. Depth, see sections on Plate 7; thickness, 10 feet 2 inches; caved and closed.
New County		do	60 acres mined. Too thin to mine, except on mountain side.
Clark		do	404 acres mined. Depth, see sections on Plate 7; thickness, 7 feet 7 inches; caved and closed.
Dunmore Nos. 1, 2, and 3.		do	4 acres mined. Now beginning to be opened.

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

Delaware, Lackawanna & Western Coal Co. collieries—Continued.

CAYUGA COLLIERY AND STORRS COLLIERY.

(Work section between Keyser Valley and Leggetts Creek, from Bloom Avenue to foot of West Mountain.)

Coal b			General conditions.
Eight-foot..			Eroded.
Five-foot...			208 acres mined. Depth, see sections on Plates 11 and 13; thickness, 4 feet 8 inches, includes 8 inches of refuse; pillars now being removed; space stowed with gob and surplus rock from a lower bed.
Four-foot..			168 acres mined. Depth, see sections on Plates 11 and 13; thickness, 4 feet, includes 8 inches of refuse; falling roof, 2½ feet thick, closes the mine after standing; now mining top split of Four-foot, 20 inches thick, and stowing surplus rock in 5-foot vein.
Diamond..			490 acres mined. Depth, see sections on Plates 11 and 13; thickness, 8 feet, includes 8 inches refuse; caved in many places; bad fire-clay roof which falls soon after working stops; pillars strong.[a]
Rock......			174 acres mined. 11 and 13; thickness, 3 feet 2½ feet of roof for height;
Big........			623 acres mined. Depth, see sections on Plates 11 and 13; thickness, 10 feet, 1 foot 3 inches refuse; old mine caved and closed.
New County			Not mined; too thin.
Clark.......			576 acres mined. Depth, see sections on Plates 11 and 13; thickness, 8 feet, includes 2 inches refuse; many local falls, but no general squeeze; workings now being flushed with culm.
Dunmore No. 1.....	....	Not mined..	Not mined, but now being opened.
Dunmore No. 2.....	....	......do..	Not mined; opening in preparation.
Dunmore No. 3.....	....	......do..	Do.

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist as those under Hyde Park, where many thick beds lie close together and the pillars in the several beds are not columnized; the pillars of an upper bed are thus permitted to break through the strata which separate the seams into the chambers or openings of an underlying bed.

People's Coal Co.

OXFORD COLLIERY.

(Works Hyde Park section, from the river to South Main Avenue, between Lackawanna and Luzerne Streets.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot, four-foot		Not mined	Not mined at present.
Diamond	No. 14	Depth, 262 feet; approached to point under northwest corner of building; solid pillar under rest of school lot; bed, 10 feet thick; falls in room approaching school; conditions good.	84 acres
	No. 16	Depth, 200 feet; caved and inaccessible; approached to edge of coal worked by Bridge Coal Co.	
Rock	No. 14	Depth, 294 feet; inaccessible; worked from Hampton colliery	104 acres mined. Depth, see sections on Plate 17; thickness, 8 feet 2 inches, with 1 inch refuse; over 5 acres caved under No. 16 School; pillars sound surrounding cave, and no indications of spread of cave; [a] parts of Oxford working effectually flushed with culm.
	No. 16	Depth, 229 feet; caved and inaccessible; worked by Bridge Coal Co.	
Big	No. 14	Depth, about 364 feet; inaccessible, caved, and flushed	116 acres mined. Depth, see sections on Plate 17; thickness, 12 to 18 feet, with 2 to 3 feet of refuse; pillars and chambers of usual size; local falls, but no serious chipping or other indications of extension of cave, beyond 1 or 2 acres under Schoo lNo. 16.[a]
	No. 16	Depth, 289 feet; inaccessible on account of cave; pillars surrounding cave appear in fair condition and usual size; a few local falls, but no indications of extension of caving; worked by Bridge Coal Co.	
New County	No. 14	See Hyde Park colliery, page 29.	120 acres mined. Depth, see sections on Pl 10 feet, with 1 to 2 feet of refuse; standing, strong; roof good; no squeezing; [a] no caving under No. 1
	No. 16	Depth, about 334 feet; pillars standing in good condition and well distributed; no local falls; no present indication of settlement.	
Clark	No. 14	Depth,	104 acres mined. Plate 17; thickness, 7 to 13 feet, openings large, but pillars firm, slight chipping, but no present e.
	No. 16	Depth,	

[a] Surface subsidence may and often does occur where pillars are strong, and without much warning or crushing of pillars, if conditions exist such as those under Hyde Park, where many thick seams lie close together and the pillars in the several beds are not columnized; pillars of an upper bed are thus permitted to break through the intervening strata into the chambers or openings of an underlying bed.

People's Coal Co.—Continued.

OXFORD COLLIERY—Continued.

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Dunmore No. 1.....	No. 14............	Depth, 516 feet; mined under northeast and southeast side, but major part solid; chambers well filled with gob, and mining stopped.	21 acres [illegible] 1 foot bench pillars, access- Dun- more coal.
	No. 16............	Depth, 461 feet, not mined.	
Dunmore No. 2.....	No. 14............	Depth, [illegible] eastern part lid coal; re-	73 acres mined. Depth, see sections on Plate 17; thickness, about 4½ feet, with 6 inches of refuse; roof taken down for roads, and rooms well packed with gob; pillars fairly well columnized.
	No. 16............	Depth, [illegible] east side of	
Dunmore No. 3.....	No. 14............	Depth, [illegible] eastern part ently mined.	62 acres [illegible] sections on Plate 17; thickness, about vith 1½ feet of refuse; recently mined, vell columnized; rooms filled with gob, s.
	No. 16............	Depth, [illegible] of school lot; e.	

Delaware & Hudson Canal Co. collieries.

VON STORCH COLLIERY.

(Works Providence section, river to mountain, between Clearview and Putnam Streets, from river to Cayuga line, between Putnam and William.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		No schools	Worked and robbed.
Five-foot	No. 24 No. 25	Depth, 55 feet; pillars sound; conditions fair. Depth, 37 feet; large pillar under entire school lot.	104 acres mined. Depth, see sections on Plates 7 and 8; thickness, 4 feet 9 inches; 1 inch of refuse; fireclay roof, which falls; pillars well distributed and look good; rooms well packed with gob, inclusive of roadways when finished.
Four-foot	No. 24 No. 40 No. 25	Depth, 147 feet; inaccessible; all openings filled with gob See West Ridge colliery, page 23. Large pillars under half of school lot; mined under other half; chambers filled; much pressure on pillars from effect of squeezing in Dunmore bed; passageway along east side of Big pillar.	165 acres mined. Depth, see sections on Plates 7 and 8; thickness 3 feet clear; chambers well filled with gob; many parts roadway also filled.
Diamond		Caved; abandoned; inaccessible.	365 acres mined. Depth, see sections on Plates 7 and 8; thickness, 10 to 15 feet, includes 2 to 4 feet refuse. This bed carries 10 to 15 feet of falling fireclay roof which soon disintegrates and falls, filling all openings.
Rock	No. 24 No. 40 No. 25	Depth, 235 feet; solid, and too thin to mine here Depth, 260 feet; caved and closed. Depth, 216 feet; solid under school lot; mined on west side only at present; vicinity of School No. 25 shows signs of squeeze.	395 acres mined. Depth, see sections on Plates 7 and 8; thickness, 3 feet 6 inches; 2 inches of refuse; falling roof; rooms filled with gob and falling roof.
Big		Caved and closed	397 acres mined. Depth, see sections on Plates 7 and 8; thickness, 11 to 13 feet; closed throughout.
New County		Not mined; to date considered too thin to mine	6 acres mined.
Clark		Caved and closed	489 acres mined. Depth, see sections on Plates 7 and 8; thickness, 7 to 9 feet; caved and closed throughout.
Dunmore beds		These beds mined by West Ridge colliery (see p. 23). No. 40 School undermined from this colliery in Diamond, Big, and Clark beds, but workings are caved and closed.	

Delaware & Hudson Canal Co. collieries—Continued.

LEGGETTS CREEK COLLIERY.

(Works north Providence section, bounded by East Market Street, North Main Avenue, and the city line.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Eight-foot		Eroded	Eroded.
Five-foot	No. 44	Worked out and abandoned	33 acres mined. Depth, see sections on Plates 10 and 11; thickness, 3 feet 6 inches to 5 feet; worked out and abandoned.
	No. 26	Eroded.	
Four-foot	No. 26	Depth, 66 feet; inaccessible; filled with rock or gangway fallen	263 acres mined. Depth, see sections on Plates 10 and 11; thickness, 3 feet 6 inches; chambers well filled with gob.
	No. 44	Accessible, pillars sound; conditions fair.	
Diamond	No. 24	Depth, 212 feet; ... abandoned	263 acres mined. ... on Plates 10 and 11; thickness, 8 feet ... 15 feet of falling roof of fireclay and ... and closed all openings throughout.
	No. 26	Depth, 135 feet; ... abandoned.	
	No. 44	Caved, closed, a...	
Rock	No. 24	Dept...	98 acres mined. Depth, see sections on Plates 10 and 11; thickness, 2½ to 3 feet; rooms well filled with gob on both sides; conditions fair.
	No. 26	Dept... gob both sides of roadway; pillars	
	No. 44	Now ... walls both sides; no signs at pre... re bed; conditions fair.	
Big		This bed flushed under School No. 26 and caved and closed under Nos. 24, 25, and 44; west half of School No. 25 is over solid pillar in all veins.	375 acres mined. Depth, see sections on Plates 10 and 11; thickness, 11 to 12 feet; mined and abandoned long ago; now caved and closed.
New County		Too thin to mine	Not mined; too thin.
		This bed reported closed under all schools	206 acres mined. Depth, see sections on Plates 10 and 11; thickness, 8 feet; mined, abandoned, and closed.
	No. 26	See Dickson colliery, page 38.	
Dunmore No. 1		Not mined; too thin	Not mined; too thin. Bottom split of Dunmore No. 1 is here known as Dunmore No. 2.
Dunmore No. 2	No. 26	Depth, 531 feet; very thin; not worked	51 acres mined. ... thickness, 1 to 2½ ... This bed at this colliery is known as No. 3.
	No. 44	2½ feet thick; rooms filled with gob.	
Dunmore No. 3 (here known as No. 4).	No. 24	Depth, ... ed with rock;	333 acres mined. Depth, see sections on Plates 10 and 11; thickness, ... ; rooms fair, all ... large or strong ... squeezing is in ... remains intact ... No. 4 Dunmore.
	No. 25	Depth ... f school, this ... approaching	
	No. 26	Depth ... ush pipe laid ..., which, judg-	
	No. 44	Closed	

MARVINE COLLIERY.

(Works between Providence and the city line, from Florida Street to Dunmore and Olyphant Road.)

Eight-foot		Eroded	Eroded.
Five-foot	No. 44	Near surface; worked out and abandoned years ago	150 acres mined. Depth, see sections on Plates 9 and 10; thickness, 5 to 8 feet, includes 2 to 3 feet of refuse; bottom bench, 5 feet thick, mined only; this bed mined from Richmond drifts; abandoned and inaccessible.
Four-foot		Operated from Leggetts Creek colliery (see p. 36)	See page 36.
Diamond	No. 44	See Leggetts Creek colliery, page 36	135 acres mined. Depth, see sections on Plates 8 and 10; thickness, 9 to 10 feet; bad falling fireclay roof; now being mined under Marvine farm on east side of mine; on west side now reopening caved area caused by recent general squeeze.
Rock	do	See Leggetts Creek colliery, page 36	This vein not mined at Marvine colliery.
Big	do	Mined, abandoned, and caved	445 acres on Plates 9 and 10; thickness, wo splits on east side, where it Marvine farm where there are
New County		Not mined; too thin	Too thin to mine.
Clark	No. 44	Worked from Leggetts Creek colliery (see p. 36)	242 acres mined. Depth, see sections on Plates 9 and 10; thickness, 5 to 6 feet; largely caved and closed on west side; open and partly mined on east side; few improvements on surface east side.
Dunmore No. 1	do	See Leggetts Creek colliery, page 36	Too thin to mine.
Dunmore No. 2			53 acres mined. Depth, see sections on Plates 9 and 10; thickness, 2½ to 3 feet; not much mined as yet.
Dunmore No. 3		No schools over the Marvine workings	74 acres

Delaware & Hudson Canal Co. collieries—Continued.

DICKSON COLLIERY.

(Works Green Ridge section from the river to the Dunmore line and from Delaware Street to Columbia Avenue.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
All beds above Big		Eroded	Eroded.
Big	No. 27	Just over the line on Pennsylvania Coal Co. land and not undermined.	101 acres mined. Depth, see sections on Plates 6 and 8; thickness 12 feet; includes 2 feet 4 inches of refuse; workings stopped account thin cover of sand and gravel; standing pillars fair.
New County		Contains too much refuse to mine at present. About 5 feet thick.	
Clark	No. 27	Depth, 226 feet; this school on Pennsylvania Coal Co. land, near land line; not mined; roll passes under school.	194 acres mined. Depth, see sections on Plates 6 to 8; thickness of 8 feet includes 9 inches of refuse; pillars standing in fair condition; local falls, but no squeeze as yet.
Dunmore No. 1	do	Depth, 289 feet; near to land line on Pennsylvania Coal Co. land; not mined.	83 acres mined. Depth, see sections on Plates 6 and 8; thickness, 2 feet 2 inches; well mined over; rooms well gobbed; pillars sound; conditions fair. This is bottom split of the bed and is here known as Dunmore No. 2, top split being called No. 1.
Dunmore No. 2	do	Just over line on Pennsylvania Coal Co. land; not mined	50 acres mined. Depth, see sections on Plates 6 and 8; bed rather thin, and therefore not extensively mined; where mined, rooms filled and conditions fair; here known as Dunmore No. 3.
Dunmore No. 3	do	Depth, 384 feet; just over line on Pennsylvania Coal Co. land; not mined.	351 acres mined. Depth, see sections on Plates 6 and 8; thickness, 3 to 3½ feet; well mined over; pillars generally sound; rooms well filled with gob; conditions fair.

Manville colliery—Operated jointly by the Delaware, Lackawanna & Western and Delaware & Hudson Companies.

(Works Green Ridge section, from the river to the Dunmore line, between Larch and Delaware Streets.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
All beds above the Big vein.	....	Eroded....................	Eroded.
Big....................	No. 21............. Nos. 28 and 34.....	Worked by Diamond colliery. (See p. 31).......... Eroded....................	Eroded, except small area on west side of river; worked by Diamond colliery and now caved.
New County	No. 21............. No. 28............. No. 34.............	Depth, about 160 feet; not mined; workings not extended under school. Depth, about 100 feet. Depth, about 170 feet; not mined.	16 acres mined. Depth, see sections on Plates 5 and 6; thickness, 5 feet 9 inches; includes 2 feet of refuse; twin bed carries top split 3 to 4 feet thick, separated from main bottom split by 8 to 10 feet of rock; mining only recently begun; chambers, 24 feet; pillars, 36 feet.
Clark....................	No. 21............. No. 34............. No. 28.............	Depth, about 261 feet; inaccessible on account of water.......... Depth, about 220 feet. Depth, 180 feet; workings accessible; openings large; pillars chipped considerably, more on account of weight than air slacking.	315 acres ; thickness ooms large; onsiderable nine, chip- n from air now caved
Top Split (here known as Dunmore No. 1).	....	Not mined....................	Not mined.
Dunmore No. 1 (here known as No. 2).	No. 21............. No. 34.............	Depth, about 325 feet; pillars sound and as shown, rooms filled with gob, except roadway. Depth, 267 feet; pillars sound and as represented; rooms filled with gob, except roadway.	215 acres
Dunmore No. 2 (here known as No. 3).	No. 21............. No. 34............. No. 28.............	Depth, about 365 feet; pillars sound and well distributed; rooms full of gob, except roadway in center; openings large; conditions fair Depth, 387 feet; pillars sound and rooms full of gob, except roadway in center. Depth, 285 feet; workings inaccessible; reported filled and settled.	330 acres
Dunmore No. 3 (here known as No. 4).	No. 21............. No. 34............. No. 28.............	Depth, naps; rooms filled air. Depth, rooms filled with Depth, n on maps; rooms ions fair.	311 acres and 6; thickness to 4 feet bottom h sides of 10 or 12 and sound, but orted. This bed

Pennsylvania Coal Co. colliery.

NO. 2 SHAFT COLLIERY.

(Works Petersburg section, between Myrtle Street and Dunmore, east of Taylor Avenue.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Beds above the Clark.		All eroded	1 acre mined. All beds above the Clark are eroded.
Clark	No. 5	Depth, 30 feet; pillars standing firm and sound; no falls; good roof.	20 acres mined. Depth, see sections on Plates 4 and 24; thickness, 5 feet; 1 foot bottom lifted in roads; chambers one-sixth full of gob, old mine, pillars strong; company now reopening, preparing to flush with culm and reclaim pillars.
Dunmore No. 1	do	Depth, 170 feet; pillars strong and well distributed; no signs of weakness; good roof.	105 acres
Dunmore No. 2	do	Depth, 200 feet; pillars strong; roof excellent; condition good	73 acres mined. Depth, see sections on Plates 4 and 24; thickness, 5 feet 7 inches; 3 inches of refuse; pillars strong and well distributed; no signs of weakness; pillars near outcrop being reclaimed.
Dunmore No. 3	do	Depth, 260 feet; not mined	16 acres mined. Depth, see sections on Plates 4 and 24, thickness about 3 to 4 feet; not much mined.

Green Ridge Coal Co.

GREEN RIDGE COLLIERY.

(Works small area in city between Ash and Poplar Streets and between Monroe and Taylor Avenues.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Clark		No schools over these workings	Formerly ... being mined to ... d with gob and ... w settling some- ... t 175 feet. (See
Dunmore No. 1		do	Depth, 2
Dunmore No. 2		No schools over this bed	Depth, ... feet; ... and
Dunmore No. 3, China vein.		do	Mined and caved under city; now inaccessible; depth, 303 feet (see sections on Pl. 4); thickness, 3 to 4 feet.

North End Coal Co. colliery.

NORTH END COLLIERY.

(Works the upper beds near Leggetts Gap.)

Coal beds.	Name of school.	Mining conditions under school properties.	General conditions.
Beds above Diamond.		Eroded	Eroded.
Diamond	No. 23	do.	Company remining old workings; now being worked along outcrop on steep dip and under mountain side, where few improvements exist on surface.
Rock	do	Outcrops under school; pitch, 45°; thickness, 3 to 4 feet; pillars, good size; conditions fair at present, but pillars should not be disturbed.	Company remining old workings (see sections on Pls. 11 and 13); thickness, 3½ feet; divided bed in eastern part; top bench, 3 feet; rock, 3 feet; bottom bench, 3 feet 2 inches; dip of bed about 45°; crop falls liable on surface if upper pillars are removed.
Big	do	Pitch, 45' on from pillar.	Company remining old workings; thickness, 15 to 26 feet, dip, 45°; openings large; large crop caves liable to occur if pillars are removed.
New County	do	Depth, 275 to 336 feet; pitch, 50°; lowest workings are north of school; thickness, 1½ feet; not mined under school.	Company remining old workings (see sections on Pls. 11 and 13); bed very thin; only mined near outcrop.
Beds below New County.		See Cayuga colliery, page 32.	Not mined by North End colliery except in mountain side near outcrop.

Clearview Coal Co. colliery.

(Works South Providence north of Clearview Street, strip 200 feet wide, from North Main Avenue to Keyser Valley Branch of Delaware, Lackawanna & Western Railroad.)

This colliery is now engaged at second mining in the two top beds under above locality. These openings are expected to extend eventually under School No. 40, but will not reach this point for several years. The operation is small, and the output is delivered by wagons.

Bull's Head Coal Co.

(Works near junction of North Main Avenue with Providence Road.)

This colliery is engaged at second mining of the Diamond and the top split of the Four-Foot beds under Winton, Church, and Nassau tracts in above locality. No school improvements on these lands. Operation for local consumption, and delivery by wagon.

Mountain Lake Coal Co.

(Works on mountain side near Mountain Lake, east of Laurel line.)

This mine works an island of coal in Dunmore bed on mountain east of Laurel line, for local consumption; delivery by wagon. No surface improvements over the coal bed.

OBSERVATIONS ON PRESENT MINING CONDITIONS UNDER SCRANTON.

INTRODUCTORY STATEMENT.

As stated in the chapter on the history of anthracite, the mining methods pursued in the earlier days of the industry, not only in Scranton, but everywhere in the anthracite fields, were not conducted with the view of ultimately mining the maximum amount of coal, with the least effect upon the surface, but with a view to immediate profits. Hence, little attention was given to surveying and engineering in the early mines, and great irregularity in the method of mining was the rule rather than the exception. This irregularity makes it exceedingly difficult to columnize pillars now where mining is being done in the solid under worked-over portions of higher coal beds.

To illustrate this particular point reference is made to the tracings that show the mine workings under the various school properties and are in the possession of the board of school control. These tracings are included in the report made by Messrs. Stevenson and Knight. In the more recent mining under the city, the attempt has been made to remedy this defect, and this attempt has been fairly successful.

As the result of our inspection of the mines under Scranton, as given in detail on preceding pages, we have grouped the mine workings into several classes; in each of these classes approximately similar conditions obtain, and to each the same remedies for sustaining the surface might apply, as stated below:

SURFACE BEDS.

WEST SIDE OF LACKAWANNA RIVER.

On the west side of the Lackawanna River, at the Dodge, Hyde Park, Mt. Pleasant, Diamond, Brisbin, Cayuga, Von Storch, and Leggetts Creek collieries, the surface beds being mined are known as the Eight-foot, Five-foot, and two splits of the Four-foot.

As before stated there is only a small area underlain by the Eight-foot; the areas underlain by the other beds gradually increase in size, as the beds are lower in the measures.

In mining these beds efforts have been made—with a fair degree of success—to columnize the pillars, and about the usual percentage of coal, approximately 33⅓ per cent on first mining, is left in for support of the overburden. In a few places reclamation of pillars, or what is commonly termed "robbing," is in progress, but only where there are comparatively few surface improvements. The menace to the surface from the mining of these beds, as at present conducted, is comparatively slight. When the time comes, however, for the reclamation of pillars from the greater part of the area mentioned, serious surface disturbance may be expected, unless in the meantime some method of support is introduced. Suggestions on this point are given on subsequent pages.

SOUTH AND EAST SIDES OF THE LACKAWANNA RIVER.

On the south and east sides of the Lackawanna River, at the National mine, the Big and the New County beds are nearest the surface under a part of the property, the Clark vein under another part, and the Dunmore No. 2 under still another part. The part underlain by the New County and Big beds carries few improvements and is much caved, so that no serious result is likely to occur by reason of the extraction of the remaining pillars. The mined-over part of the Clark bed, as will be noted from the plans, underlies a larger area than the mined-over part of either of the two overlying beds; and before extraction of pillars from the Clark bed is begun, measures for the support of the overburden should be adopted where the surface improvements are of sufficient value to justify the expense. This observation refers particularly to the part of the bed formerly worked from the old Meadow Brook mine; it underlies a thickly settled portion of the south side.

As will be noted on Plates 19, 20, and 21 the Dunmore No. 2 is the surface bed over a considerable portion of the National and Meadow Brook operations, extending from Beech Street to Sanders Street, and from the Erie & Wyoming Valley Railroad to the Lackawanna River. Examination of workings in this bed, and inspection of the mine maps, indicate that considerably less than the usual one-third has been left in pillars for support. There is no mining now in progress in this bed, nor any extraction of pillars. The pillars observed under the area mentioned (particularly between Beech and Breck Streets), and between Pittston Avenue and Crown Avenue, show signs of pressure and should not be disturbed. Although it is true that these pillars have stood without serious subsidence for many years, there is a possibility of a "creep" or "squeeze," such as would unquestionably cause surface damage in the area just mentioned, starting at almost any time. Remedial measures should be applied in the Dunmore No. 2 bed in this area at the earliest possible moment, before a creep or squeeze starts, as the conditions are such that if once started, no remedies that might be attempted, and hastily applied, would be effective in preventing a general subsidence of practically all the above mentioned area.

CENTRAL PART OF SCRANTON.

The Pine Brook colliery of the Scranton Coal Co. includes a large area in the central part of the city of Scranton, as will be noted from Plates Nos. 1, 2, 3, 4, 5, and 22. This area extends eastward from Beech Street on the south side to Poplar Street at the Dunmore line, and from the Lackawanna River to the outcrop of the Dunmore beds near Nay Aug Park.

Under a portion of the territory mentioned, the Big or Fourteen-foot bed is present. It was partly worked over many years ago by the old Lackawanna Iron & Coal Co. The area underlain by this bed is what is generally known as Sanderson Hill, and is clearly shown in Plates Nos. 2, 3, and 4. The old workings in the Big bed are inaccessible, except a very small portion that extends from the Pine Brook Traveling Way to a point under the Central High School. Although there may be other openings to the workings in this bed, they are unknown to us. From information furnished by various persons, it is believed that the old maps of the workings in this bed are reasonably accurate.

The part of these workings that was inspected showed the pillars in good condition and the roof over the openings fairly sound, although local falls have occurred in many openings preventing access to points beyond. According to our information no serious "creeps" or "squeezes" have occurred in this bed, and unless some disturbance takes place through subsidence of the measures below it not much danger is to be apprehended from a general creep in this bed. We are, however, of the opinion that detailed investigations should be made by reopening small holes through the local falls mentioned above, and by sinking shallow shafts at various points for the purpose of making accurate surveys of the mine workings. These should be maintained as avenues through which to conduct or transport material for filling. It is deemed especially important that these openings be completely filled, on account of the nearness of this bed to the surface, and the value of the surface improvements. Methods of protection will be described in another chapter.

Below the Big bed the next bed that has been worked from the Pine Brook shaft is the Clark. The New County bed has not been worked at Pine Brook, but it is present and will doubtless be mined in the future. The Pine Brook workings include what was formerly the property of the Fair Lawn Coal Co., between Gibson and Ash Streets, and Capouse and Quincy Avenues. The usual rule of leaving approximately one-third of the coal was generally followed in the major part of the workings from the Pine Brook shaft, but much less than one-third was left in the Clark bed where worked from Fair Lawn. This bed is from 8 to 11 feet thick; a bench of coal at about the middle of the bed that is considerably softer than the balance was noted. This bench is affected by what is known as "air slack," causing it to chip and flake off, and to show the first signs of any undue pressure on the pillars.

A very large proportion of the pillars inspected an this bed show unmistakable signs of pressure, particularly in the Fair Lawn workings and outwardly from this area for a considerable distance. These signs of pressure on the pillars can not, in our opinion, be solely attrib-

uted to air slack, but are, we believe, the first stage of a creep or squeeze that if fully started may result in the complete collapse of the pillars in a large part of the area mentioned; it would bring down the roof, and unquestionably affect the surface. These indications, as before stated, are most serious in the Fair Lawn workings; they are observed on both sides of the tract and under the portion of the property where the Big Vein is present. Should a general squeeze take place in the Clark bed workings it would certainly affect the pillars and overlying strata of the Big bed and result in a very serious disturbance of the surface.

We deem it important to lay particular stress on the necessity for promptly taking measures to prevent the *starting* of a general squeeze or creep in the Clark bed at the Pine Brook colliery; for such a squeeze might cause breakages of gas, water and sewer mains, and resultant damages.

A point of particular weakness in this bed is under the Technical High School, near the intersection of Adams Avenue and Gibson Street. We have been informed that the Scranton Coal Co. has begun flushing culm into the workings under this important building, and that it is their intention to fill these workings as rapidly as possible. When this flushing is completed and a block of 1 or 2 acres is completely flushed, it will strengthen not only the point immediately filled, but have a tendency to support the roof for some distance on all sides of the artificial pillar thus introduced.

The old Lackawanna Iron & Coal Co. opened and worked the Clark bed by a drift from Roaring Brook gorge, near the Laurel line station. These old workings are now inaccessible, but maps inspected show an area worked over on the north and east sides of the river bank between the Delaware, Lackawanna & Western Railroad and Vine Street, and Madison and Clay Avenues. The maps show that very small pillars were left in. The old workings should be opened and artificial pillars made by flushing. The same plan is suggested for the Big, or Fourteen-foot, bed under Sanderson Hill, and for the old Iron Co. workings in this bed on the south side of Roaring Brook, under Spruk's lumber yard and vicinity.

At the Manville colliery, operated jointly by the Delaware, Lackawanna & Western and the Delaware & Hudson Companies, the surface bed is the New County. This bed has been attacked recently, and is now being mined under the Green Ridge section of the city. It averages about 6 feet thick, with nearly 2 feet of refuse in several benches. We were informed that under the old leases the lessees were prohibited from mining this bed, but by a recent modification of the terms of certain of the leases they are permitted to extract one-third of the bed, leaving two-thirds as pillars to support the overburden. Considering the depth at which the bed lies and the char-

acter of the overlying strata, we do not think there is much danger to the surface from mining this bed, if not more than one-third of the coal is extracted.

At this colliery the Clark bed has been worked over the whole of the area tributary to the mine, as will be noted from Plates 5, 6, and 7, and is at present abandoned, no solid or pillar mining being in progress. About the usual one-third of the coal has been left to support the roof. Many parts of these workings are inaccessible because of local falls, and a small part of the workings has been filled with culm, principally under surface improvements controlled by the mining company.

The pillars in this bed show the usual chipping, due to air slack, and in some places signs of squeeze or creep, particularly in the vicinity of Poplar Street and between Capouse and Washington Avenues. The boundary pillar between the Manville workings and those of the Pine Brook mine is very small, and would not be of sufficient strength, in our opinion, to break off or stop a squeeze that might originate on either side of it. We are of the opinion, therefore, that filling or other remedial measures for the support of the overburden should be started in portions of the Manville Clark-bed workings, as we recommended at Pine Brook.

At the Dickson mine of the Delaware & Hudson Co. the surface bed is the Big, or Fourteen-foot, which is 10 to 14 feet thick. This bed was worked some years ago between the river and Dickson Avenue and between Delaware and Market Streets; a very small part east of Sanderson Avenue was also worked.

No mining, either of solid coal or pillars is now being done in this bed. There is, however, a considerable block of solid coal east of Sanderson Avenue that may at some time be extracted. If mining is resumed in this bed it should be conducted with great care, as the bed is close to the surface, and the overlying strata are weak.

Parts of this bed west of the Delaware & Hudson Railroad and under the Lackawanna River have been flushed with culm, and the balance of the workings should be filled in the same manner. The possibility of recovering the pillars in the worked-over part of this bed without serious damage to the surface is, in our opinion, decidedly doubtful, even though the openings may be completely filled with culm or other flushed-in material.

The New County bed has not been worked at the Dickson mine, being considered too thin and impure for profitable extraction. This bed, however, may be mined hereafter.

The Clark bed has been mined in about the same manner as at Pine Brook and Manville, and the same remarks regarding conditions apply. Portions of this bed also have been filled with culm, particularly toward the Lackawanna River.

MIDDLE BEDS.

HYDE PARK AND PROVIDENCE SECTIONS.

As before mentioned, under Hyde Park and Providence, the middle series of beds, the Diamond, Rock, Big, New County, and Clark (especially the first three of these), are quite thick and the intervening strata are comparatively thin and weak. On account of the failure in the past to columnize pillars, the workings in these beds, where now open, constitute a serious menace to the surface, and this portion of the city will be the most expensive and difficult to protect. However, it should be noted that very large areas of the three uppermost beds have been closed by crushing of the pillars and strata in the past. This condition was observed in parts of the Bellevue, Hyde Park, Hampton, Oxford, Mount Pleasant, Diamond, Brisbin, Cayuga, Von Storch, Leggetts Creek, and Marvine mines. Where such complete crushing of the pillars, with consequent subsidence of the overlying strata and surface, has taken place in the past, no serious apprehensions need be entertained of future damage to the surface improvements, unless, in the process of mining lower veins, insufficient pillar support is left to carry the overburden and a creep or squeeze takes place. This has been the case recently at the Leggetts Creek mine in mining the lower Dunmore bed at a depth of 700 feet, where was applied the usual though here insufficient rule of leaving about one-third of the coal for support.

Where the workings in these thick and closely lying beds are not closed by a general crush (and no one knows how large or extensive such openings may be) there is always a liability to a repetition of the same kind of subsidence as that which wrecked No. 16 School. In this connection attention is particularly called to the conditions existing under No. 12 School. Here the Diamond bed is very near the surface, within 13 to 40 feet. Second mining is now in progress to win bottom coal formerly left in this bed, and the New County bed is being mined. An attempt is being made to drive openings in the New County bed under openings in the Big bed, but this attempt is not altogether successful. These conditions, we believe, are quite similar to those formerly existing under No. 16 School.

We strongly recommend that the pillars in the Diamond, Rock, Big, and New County beds under this building should not be disturbed, and that the openings in the Diamond, Rock, and Big beds should be filled as promptly as possible. Such filling could easily be done by drilling one or two bore holes in the school lot. The filling of openings should not be confined to the school lot only, but should extend outside the lot some distance, as there is danger in case of a cave in any seam, of the side pull damaging the building.

It is also deemed important to refer particularly to No. 23 School, where the Rock and the Big bed pillars now in place should not under any circumstances be disturbed, neither under the school lot nor for some distance outside of it, as shown by the maps formerly submitted to the school board by the North End Coal Co. We also suggest that the openings under this school property should be flushed full of sand, culm, or other material.

The best manner of applying an effective remedy for this serious menace is difficult to determine, because the openings are so large, on account of the thickness of the seams, and there is the difficulty of procuring the material for this purpose.

DUNMORE BEDS.

The deeper-lying Dunmore beds under the major portion of the city, constitute a class by themselves. They are in many places so thin that during mining much top or bottom rock has been removed in all the gangways and along roads in the chambers to make room for cars and mules. This rock with the large quantity of interstratified refuse that is usually present in the coal beds nearly fills the mined-out space when stowed in the chambers, and thus constitutes a check to quick or total subsidence. Then, too, the thickness of the rock over the coal is generally so great that local caves in the workings are not likely to affect the surface. The greatest menace to the surface property from these deep thin beds is through a general subsidence—a creep or squeeze extending over large areas. Even then the settlement will be gradual, and as a rule so uniform as to cause little or no damage to surface property, except where the uniformity of the subsidence is interrupted or prevented by the presence of very large pillars or solid blocks of unmined coal, in which event, buildings located on the surface over or near the margin of such large pillars will be liable to considerable damage by the side pull, or uneven subsidence.

In consequence of these facts we would advise as a measure of preventing damage to surface improvements over these deeper beds that the Dunmore beds be mined in the usual manner under large blocks of coal now held as reservations in any of the coal beds overlying the Dunmore and not at present mined nor intended to be mined.

RECAPITULATION.

Thus, to recapitulate, we have three general sets of conditions which naturally divide the coal workings into as many separate classes, to wit:

1. The surface beds, viz, on the west side, the Eight-foot, Five-foot, and Four-foot; on the east side, the Big, New County, Clark, and Dunmore No. 2, of which the latter are surface beds under different parts of the south side and central city sections.

2. The middle series of beds, viz, Diamond, Rock, Big, New County, and Clark, under the Hyde Park and Providence sections.

3. The three lowest beds, Dunmore No. 1, Dunmore No. 2, and Dunmore No. 3, under the major part of the city.

METHODS FOR SURFACE SUPPORT.

The methods employed at the present time for supporting the surface over the coal mines under the city of Scranton are of two general classes, which may be termed natural and artificial.

NATURAL OR PILLAR SUPPORT.

The natural method, of course, consists in leaving pillars of coal sufficiently strong to support the weight of the earth and rock that overlie the coal bed. The efficiency and value of these supports depend upon their size. That is, the horizontal area, the height of the pillar (which is fixed by the thickness of the coal bed), the compressive strength of the coal, the regularity of distribution of the pillars, and whether or not they are columnized with respect to pillars in near-by overlying or underlying beds, all have to be considered. In this vicinity the size of pillars has been mainly regulated by the one-third rule previously mentioned.

ARTIFICIAL SUPPORT.

FLUSHING.

There are several artificial methods of roof support, the principal and most effective of which is known as the flushing method. In this method coal culm and other fine refuse is washed into the mines through pipes by means of a stream of water, thus filling the desired portions of the mine.

This method was first used at Shenandoah, Pa., by the Philadelphia & Reading Coal & Iron Co. Afterwards it was introduced at Plymouth, Pa., and now has been adopted and is in practice over the whole anthracite region. Only culm is used, and the method has been adopted mainly for the purpose of protecting those parts of the mine or of the surface which it is necessary to support in order to maintain the mining operations.

Under Scranton considerable flushing has been done at various places, as indicated in the chapter on "Present mining conditions." Foreign engineers, after inspecting the process in this country, have adopted it in Europe. There, much extended and amplified, it is now an essential part of the more recent mining methods by which the engineers are able to recover all the coal; the excavated spaces are filled by the flushing method with crushed rock, sand, gravel, and soil obtained from quarries opened for the purpose, and also with ashes and city refuse, some of which is transported long distances over the surface to the flush pipes. Foreign engineers

find that when they thus remove all the coal, a gradual though small surface settlement results, the amount of which depends upon the depth and the thickness of the coal. In this country, however, we can not hope to profitably use such expensive mining methods as may obtain abroad, because the cost of labor in the United States is very much greater and the market price of coal very much less than in Europe. The appearance of culm flushing is shown by Plate 26.

COGS.

It is frequently necessary in the course of mining to make use of some roof-supporting device that may be quickly constructed and is withal possessed of great strength. The timber crib filled with mine rock—known in mining parlance as a "cog"—has been found to answer these conditions in a very satisfactory manner, and is extensively used in all coal-mining districts. The cog consists simply of a rough crib of stout logs placed one above the other, log-house fashion, the spaces between the logs being chinked and the interior being filled with rock from the mine. (See Pl. 27 *A*.) This construction is quickly erected, and possesses great strength. Of course it is not permanent because the timbers decay in a few years. Cogs are mainly used for the purpose of stopping a settlement, squeeze or creep which the mine foreman knows to be imminent or in progress. A view of a squeezed area in the Dunmore bed is shown in Plate 29 *A*. When sufficient cogs are placed in proper localities the strata above the bed will frequently crack through to the surface, and the progress of the squeeze or creep will thus be stopped.

GOB PIERS.

Gob piers are pillars built of such refuse rock as may be readily found in most mines—mainly bony coal, fire clay, and slate. Such rock is mostly soft and does not possess very great compressive strength. Some of these piers have a square outer or inclosing wall, and are filled with mine refuse shoveled into them. In others the interior is laid up by hand and the rocks are more carefully compacted by filling the voids with fine mine refuse.

A great many such piers have been built under localities in the city of Scranton for the purpose of supporting the roof under valuable surface improvements. (See Pls. 27 *B* and 28.) The value of such piers, that is, their supporting strength, depends upon the compressive strength of the materials of which they are constructed. The value will be greater if the voids between the larger pieces are filled with the small rock and shoveled material from the mine.

GOB STOWAGE IN ROOMS.

Most coal beds consist of interstratified layers of coal, fire clay, slate, and bony coal; the three latter, of course, compose the prin-

A. GANGWAY CUT THROUGH CULM FLUSHING, OXFORD MINE.

B. GANGWAY CUT THROUGH FLUSHING, CULM STANDING AS A VERTICAL SELF-SUSTAINING WALL, OXFORD MINE.

A. TIMBER AND ROCK COG, IN BELLEVUE MINE.

B. GOB PIER IN DUNMORE NO. 2 BED, NATIONAL MINE.

cipal refuse material of the mine. In all the mining methods adopted under the city of Scranton, all the material of the coal beds that is not coal is laid aside as refuse and stowed away in the chambers, either on one side or on both sides of the mine tracks. In thin beds where it is necessary to remove some of the roof rock or take up some of the floor of the mine in order to obtain height sufficient for the mules and the men to travel along the roads, much mine refuse is produced, which is also stowed in the chambers. In beds less than 4 feet thick many chambers are filled with mine refuse or gob, as it is more familiarly termed, from floor to roof. In places this gob is merely thrown in carelessly, or is shoveled in; in other localities it is packed as tightly as possible by hand. It frequently happens that the whole chamber from pillar to pillar is packed full of mine refuse. Where there is much interstratified fire clay or bone in the coal bed there will be larger quantities of the gob, and the thinner the bed the greater will be the quantity of mine rock raised or taken down for roads. Consequently, this stowage of gob in the rooms of the mines under the city of Scranton becomes an important item when the support of the surface over these coal beds is considered. As in the case of the gob piers and the cogs, the supporting value of stowed gob depends upon the compressibility of the material of which it is composed.

CONCRETE AND MASONRY PIERS.

The above methods of artificial support already mentioned are comparatively cheap to install. Some other methods of support used in the city of Scranton are concrete and sandstone piers. In these the material for construction has been introduced from the surface (through bore holes in the case of concrete or through shafts from the surface in the case of blocks of sandstone), and in the mine has been wrought into substantial piers by the use of cement. (See Pl. 29 *B*.) Though these forms of piers are much more substantial than those previously mentioned, they are also much more costly; consequently fewer of them have been installed.

IRON PROPS.

In one place, namely, in the Big bed under the Central High School building in this city, a number of iron props or posts have been installed as additional roof support. There has been no subsidence of pillars in the locality where they have been used; therefore the supporting value of the props has not been tested and their efficiency is largely a matter of opinion. In any case they are costly to install, and it is entirely probable that much more efficient means might be used for the same purpose at less expenditure.

TESTS OF ROOF-SUPPORTING DEVICES.

COMPRESSIVE STRENGTH OF ANTHRACITE.

In 1903 an exhaustive series of tests was conducted under the direction of a committee of the Scranton Engineers' Club for the purpose of determining the compressive strength of anthracite coal. The report of this committee on tests is printed in an appendix (see p. 77) to this report. The results, however, may be summed up briefly in the statement that a pressure of 216 tons per square foot will cause the average ordinary mine pillar to begin cracking, and a pressure about twice as great (432 tons per square foot) will crush it to powder.

This general statement, however, does not apply equally to all coal beds, for the tests prove a great variation in strength, even between different parts of the same bed. In some instances the weight required to crack the pillars was as low as 30 tons per square foot.

TESTS AT LEHIGH UNIVERSITY.

In order to test the value of the several artificial devices for supporting the roof of a coal mine, as well as to search out an inexpensive combination of materials which might be more cheaply installed and withal more permanent and efficient, and better adapted to certain localities than some of those mentioned, we prosecuted a series of tests at the Fritz engineering laboratory at Lehigh University, South Bethlehem, Pa., the results of which are also given in an appendix (see p. 83) to this report. A tabulated summary of the results follows, and from it mining engineers may readily compute the supporting value of any particular construction.

A. A GOB PIER IN CLARK BED UNDER CENTRAL HIGH SCHOOL BUILDING, PINE BROOK MINE.

B. SIMILAR PIER WITH FLUSH PIPE PASSING THROUGH SHOWS SUPERFICIAL CHARACTER OF MORTAR POINTING.

A. VIEW IN SQUEEZED AREA IN DUNMORE BED, LEGETTS CREEK MINE.

B. SANDSTONE AND CEMENT MASONRY PIER IN DUNMORE NO. 2 BED UNDER SCHOOL NO. 15, NATIONAL MINE.

TABLE 3.—*Results of tests of compressive strength of various forms of roof support.*

No. of test.	Construction tested.	Net tons per square foot required to produce compression of—						Compression and load (tons per square foot) at end of test.	Remarks.
		1 per cent.	3 per cent.	5 per cent.	10 per cent.	20 per cent.	30 per cent.		
1	Rectangular piers of mine rock	....	0.8	1.4	2.7	9.5	23	....	…ids not filled.
2	Circular pier of mine rock	....	3.5	5.67	11	22	28.5	Compression, 31 per cent; load, 42.5.	…filled with small
3	Timber crib filled with mine rock	....	.6	1.37	5.11	20.3	31.5	....	
4	Pile of broken sandstone; small pieces	....	....	....	4	9.3	22.4	Compression, 46 per cent; load, 104.5.	In these tests the material was not confined, but was free to expand laterally. (See appendix, pp. 84–86.)
5	Pile of small-size broken sandstone and sand.	....	....	1.6	4	13.5	35	Compression, 45 per cent; load, 144.	
6	Pile of broken sandstone; large pieces	....	3.6	5	9.1	26.4	37	Compression, 41 per cent; load, 75.	
7	Pile of coal-measures sandstone similar to No. 6.	0.8	2.1	3.5	9	53.4	....	Compression, 27 per cent; load, 56.	
8	Pile of river sand	....	....	....	....	....	....	Compression, 63 per cent; load, 108.	
9	Broken sandstone in cylinder	....	3.33	5.55	13.32	46.6	98.6	Compression, 35 per cent; load, 666.	In these tests the material was confined and could not expand laterally. (See appendix, pp. 86–88.)
10	Broken sandstone and sand in cylinder	....	3.5	5.77	24.42	308.5	....	Compression, 23 per cent; load, 636.	
11	....	....	1	1.86	5.32	10.8 5.50	25 22	Compression, 51 per cent, load, 666.	
12	r… …artly dried	2.44	5.9	14.28	35.52	138.7	444	Compression, 33 per cent; load, 668.	
13	....	.68	3	5.27	33.3	129	400	Compression, 32.2 per cent; load, 666.	
14	Wet sand flushed in and partly dried	8.4	30.2	67	173.8	555.4	....	Compression, 20.75 per cent; load, 666.	
15		9 Cracked.	84	Gradually crushed to pieces under continuous load of 45 tons.					This test was made at the Dickson Works of the Allis-Chalmers Co. in Scranton, by William Griffith.

DRY FILLING.

Although we recognize that the flushing process is the most substantial method for artificially supporting the roof of coal mines, and that it is also universally suitable for thin or thick beds and deep or shallow beds, nevertheless the method is not always applicable or convenient. There are many localities in the coal mines where it may be either preferable or permissible to resort to some of the other less efficient or less costly methods of roof support, which for one reason or another are more adaptable to a particular locality. Therefore we refer to the improvements that may be made in the different methods of dry filling.

IMPROVED METHODS OF GOB STOWAGE.

Formerly the gob of coal mines was disposed indiscriminately over the chamber at the side of the roadway, mainly for the purpose of getting rid of it at as little cost as possible. A casual inspection of the comparative table of tests on page 55 will show that well-constructed gob piers are much stronger than those indifferently built. It is also evident that in supporting the roof of coal mines, as well as in other matters, "an ounce of prevention is worth a pound of cure." The effort, therefore, should be to prevent the first small settlement, and the way in which to accomplish this effort as far as possible in the matter of stowage will be to pack the rock fragments carefully and tightly against the sides of the pillars from floor to roof, irrespective of the horizontal area occupied, and to use the fine refuse, so far as may be, to fill the voids. If the gob now contained in the thinner seams under the city of Scranton had been carefully packed so as to completely fill the space from floor to roof it would not only reinforce and preserve the strength of the coal pillars, but would present very much greater resistance to pressure and would be a much more efficient roof support than is afforded by the usual present stowage with 1 to 2 feet of space between the top of the stowed gob and the mine roof.

In some beds now working there is a surplus of mine rock which can not be stowed in the chambers and must be hauled out into other parts of the mines. If it is determined to continue thus to stow this material instead of hauling it to the surface and grinding it for flushing purposes, as has been previously mentioned (see p. 55), the purpose of roof support would be better served if the places for depositing this surplus stowage were selected with reference to the weak parts of the mines, or with reference to the support of the ground under some particularly valuable surface improvement.

Commendable work is being done along this line at the Cayuga mine of the Delaware, Lackawanna & Western Railroad; the pillars

are being extracted in a surface bed and the space formerly occupied both by the chambers and the pillars is being completely filled with surplus rock taken from a lower bed.

BLASTING ROOF AND FLOOR IN THINNER BEDS.

It is a well-known fact that loose rock occupies one and two-thirds to two times the volume of the same weight of solid rock. In other words, if a cubic yard of solid rock be broken to pieces the pieces will occupy a space of 1⅔ to 2 cubic yards.

We have conceived the idea of taking advantage of this fact for the purpose of cheaply producing an adequate roof support for certain classes of coal beds under the city. So far as we know, this method, in its entirety, has never been used before in any coal-mining district, and the suggestion is here made for the first time.

The process would be applicable to beds less than 6 feet thick and so situated that the shock of heavy blasting would not produce ruptures of the measures supporting adjacent coal beds. It consists simply in blowing up the floor of the mine to a depth equal to the thickness of the bed, and blowing down the roof of the mine directly over, to a height equal to the thickness of the bed. This would produce a total thickness of loose rock equal to three times the thickness of the coal bed. The rock would be well packed together and have great supporting power, and the process would be comparatively inexpensive.

This method might be adopted throughout the Dunmore and other thin seams, by blasting down the roof and raising the floor in the abandoned rooms or the roadways between the gob piles in the chambers. Wherever it is applied the effort should be to completely fill the whole width of the chamber or roadway from pillar to pillar, so that the loose rock will be confined between the pillars, thus greatly increasing its resistance to compression. The value and supporting power of this method of roof support and of other methods will be referred to below.

GOB PIERS AND TIMBER COGS.

There are localities under the city of Scranton where it has been deemed advisable in the past to build gob piers for the support of the roof overlying certain surface beds. The Lehigh University tests mentioned in this report show that this method of support lacks the merit of strength. The piers are very compressible, and as they have been built heretofore their supporting value is small. Their efficiency would be greatly increased, as shown by the differences between test No. 1 and No. 2 (pp. 83–84), by building them in circular form and carefully filling all the voids between the larger pieces with smaller particles of shovel stuff.

CONCRETE PIERS.

During the progress of this investigation many persons have called our attention to concrete piers as suitable for firm roof supports. This material is so costly, however, that we have hesitated to recommend it except perhaps in special cases where very valuable surface property requires unyielding support and the expense of such support is no object.

We have tested the strength of one sample of concrete composed of about the cheapest good materials available for this locality, i. e., cement, sand, and gravel. The results of this test are shown in Table 3, test 15, and Table 4, test 14 (pp. 55, 59). It will be noted that such concrete is firm and comparatively unyielding up to a certain maximum strength sufficient to cause about 3 per cent of compression and cracking, beyond which a much less weight will crush it to powder. This latter characteristic is an exceptionally bad one for a mine roof support, because such piers are liable, under the excessive stress due to a general squeeze, to collapse quickly, and thus permit the sort of caving that resembles a small though severe local earthquake in its suddenness and excessively damaging effect on the surface improvements.

DRY FILLING WITH BROKEN STONE OR SAND.

For the construction of isolated and more substantial low-cost piers in the surface beds under the city, to take the place of the gob piers for the purpose of the local support of valuable surface improvements where general flushing is not convenient, we strongly recommend the filling with broken stone or sand, or a combination of these materials, through bore holes from the surface.

Filling of this sort should be spread out by hand in the inside of the mine so that it completely fills the whole width of the space from pillar to pillar, and thus, being more or less confined has its supporting power increased. If broken stone is used the relative proportion of the voids should be ascertained and an amount of sand, coal ashes, or other fine material added sufficient to fill these voids.

By this method one bore hole 4 to 6 inches in diameter would be necessary for each pier, and inasmuch as these materials, if flushed in by water, are much more closely packed and have from ten to fifteen times the compressive strength of dry filling, it would always be wise, if water is handy or is not too costly, to flush the material in, using in some cases the city water, or the water from the gutters during the storm seasons for the purpose. The more sand there is in the mixture the better it will be, for our tests have shown that clear river sand is the strongest and least yielding material available, if it is flushed into and confined in the limits of a mine chamber; moreover it is about the cheapest material obtainable for this purpose in Scranton.

THE VALUE OF THE DEVICES FOR ROOF SUPPORT.

The following table sets forth the value of the above devices for dry filling, and also the value of the different materials that are available for flushing coal mines in this locality. The values are directly deduced from the results of the tests made by us at Lehigh University, and we think are sufficiently clear to be self-explanatory. We might add, however, that test 1 would represent the ordinary supporting value of gob piers or gob pillars. Test 2 represents the value of well-constructed gob piers, while tests 6, 7, and 8 set forth the supporting value of mine rooms filled with rock blasted from the floor and roof, as heretofore mentioned; and tests 12 and 13 indicate the supporting strength of fine materials, such as coal culm and river sand, if flushed in with water. At the bottom a comparison is made between the supporting value of the flushed culm and the flushed sand, and the concrete piers of the same nature as the sample tested.

TABLE 4.—*Supporting strength of various forms of dry filling.*

Kind of material comprising the artificial supports.	Approximate depth, in feet, of column of coal measure rock 1 foot square, necessary to compress artificial roof supports—						Remarks.
Per cent of compression	1	3	5	10	20	30	
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
1. Rectangular gob piers, ordinary construction	......	10	12	36	125	306	
2. Circular piers of mine rock well constructed	......	46	75	146	292	512	
3. Timber cogs filled with gob, average construction	......	8	68	182	270	419	
4. Loose pile of broken sandstone through 1½-inch ring, 40 per cent voids	......	....	20	53	124	298	Free to expand laterally.
5. Pile broken sandstone, 40 per cent voids, voids filled with sand	......	....	21	53	186	465	
6. Loose pile large size broken sand rock, 45 per cent voids	......	48	66	121	351	492	
7. Mine room filled with large broken sand rock, 50 per cent voids	12	27	45	117	434	a 615	
8. Mine room filled with broken sandstone, 40 per cent voids	......	44	74	177	619	1,310	
9. Mine room filled with broken sandstone, 40 per cent voids filled with sand	......	46	77	325	6,000	b 8,860	
10. Mine chamber filled with dry coal ashes, 64 per cent voids	......	13	25	70	143	332	
11. Mine room filled with dry river sand	12	40	70	442	1,715	6,640	
12. Mine room filled with river sand flushed in with water	111	522	891	2,310	....	c 8,860	
13. Mine chamber filled with coal culm flushed in with water	32	118	190	472	1,822	5,905	
14. Concrete pier, 1 part cement, 7 parts sand and gravel; 5 months old	117	1,092	Gradually cracked to pieces under continuous load equal to 600 feet of rock.				
Resistance of flushed culm	1	1	1	1	1	....	Comparative.
Resistance of flushed sand	3.5	4.4	4.7	5	4	....	
Concrete pier	3.6	9	(d)	(d)	(d)	(d)	

a 27 per cent settlement.
b 23 per cent settlement.
c 20¾ per cent settlement.
d Worthless.

SUGGESTIONS FOR IMPROVEMENT IN MINING METHODS AND PILLAR SUPPORT.

The solid coal remaining to be mined under the city of Scranton is mainly in the Dunmore beds Nos. 1, 2, and 3. These beds are from 200 to 600 feet below the surface under the greater portion of the city.

Future mining plans, we think, should provide for leaving at least 50 per cent of the coal in these beds on first mining, and the columnization of the pillars throughout all new mining as far as possible.

FLUSHING.

Reference has been made to the practice, now quite general, of flushing culm into the mines. This is being done at nearly all of the collieries within the city limits, and the method and effectiveness of this kind of support was observed by personal inspection underground (see Pl. 26).

With reference to the tests made at Lehigh University of the compressibility of the several kinds of support now in use or suggested, we are of the opinion that a practicable method for the support of the overburden, utility and cost being considered, is flushing the openings with culm, ashes, sand, broken stone, material excavated from cellars, and other stuff of similar nature that can be reduced to a size small enough to be carried in pipes with water.

As before referred to, the flushing of mines for the support of the overburden has been adopted in Europe with marked success, both in the matter of support and recovery of all the mineral, the material used for filling being sand, loam, crushed slag, and crushed stone.

It is manifest that the quantity of culm available for flushing the extensive mine openings is insufficient, even if all of that now on the surface within the city limits, together with that produced in the preparation of the present output of coal were put into the mines.

According to figures we have assembled and supplemented with estimates, it appears that there has been extracted from the beds underlying the city, approximately 221,000,000 tons of coal and other material.

The workings under the city are, of course, not all open, large areas having been closed by general caves and squeezes. It is not possible to determine the proportion of openings that have been thus closed or filled, but a conservative estimate of the space now open would be that it probably does not exceed 50 per cent of the original.

The positive protection of all of the surface would appear to require the filling with some supporting material of all of the open spaces as rapidly as the coal is extracted; but such a scheme is, of course, impracticable. It therefore remains to determine about what

proportion of the openings to be flushed would afford reasonable protection. To determine this point definitely would necessitate a much more thorough investigation and more detailed surveys than were contemplated in the general investigation upon which we are now engaged. We would, however, express the opinion that conditions could be materially improved by the insertion of artificial pillars reinforcing the natural pillars of coal in blocks of from 1 to 5 acres at points where the danger of subsidence appears greatest; such artificial pillars to be arranged with some degree of regularity, so that the overlying strata between the artificial pillar supports would act as natural bridges. This suggestion is made in order to distribute the relief measures over as large an area as possible, and to keep the burden of expense within reasonable bounds.

The fact that the best and most practicable of supports is obtained by flushing refuse material into the openings having been determined, it remains to ascertain the sources of supply of this material, and the practicable methods of handling it.

We would classify the materials obtainable, in about the following order:

CULM FROM OLD AND FROM FRESH-MINED BANKS.

Culm is now being used for flushing mine workings. We make no further comment, excepting to refer to the test of its compressibility, and to the fact that we had opportunities to observe the methods of distribution of the material underground, and to note the apparent support given to the existing coal pillars and to the overburden.

SURPLUS MINE ROCK.

The second source of supply of material, in the order of availability, we believe would be the surplus mine rock that is produced in the mining of the thin beds of coal where either roof or floor must be removed to make height. It was observed in most of the thin beds visited that considerable quantities of this material are handled, either being stowed in the chambers or loaded into mine cars and hauled to some distant point to be unloaded by hand into abandoned mine openings. While this stowage of gob affords some measure of support to the coal pillars and the roof, the compressibility of the material, as shown by the tests, is so great that the material if put in by ordinary stowage is practically useless as an effective support, particularly at great depths. We believe, therefore, that this material should be loaded into cars, hauled outside, and handled over an efficient dump and through crushing rolls of proper design for pulverizing hard materials. The ground material should then be flushed, with the culm produced at the mine, into the portions of the mine workings where it will do the most good.

In addition to this source of supply of filling material, it would probably be found practicable to install handling and crushing machinery at each of the mining operations within the city limits, to pick up refuse material, such as old rock banks, ash banks and slag, and to grade off humps and hills of earth and comparatively soft rock, and to treat this material in the same manner. The cost of handling and flushing such foreign material in connection with the going operations of the several mines, would, of course, be very much less per cubic yard than it would be in the case of an independent plant established for obtaining and handling flushing material elsewhere.

RIVER SAND.

The next source of supply of material for flushing purposes, and one that we deem of considerable importance, is the Lackawanna River. It is a well-known fact that this stream of water carries in suspension large quantities of culm, sand, and loam at all times, and especially during the flood season. Of course it is impossible to determine without careful tests the quantity of this material in cubic yards, but we do not hesitate to express the opinion that there is enough of it, and will continue to be, to justify the establishing of settling basins and of a pumping plant for distributing the material thus impounded to points in the mine workings where artificial pillars are to be inserted.

To utilize this source of supply, it would, in our opinion, be advisable either to purchase, or to procure long-term leases on, river-bottom lands at various points where suitable catch basins could be excavated, and to procure a site for a central pumping plant for the purpose of handling this material. When such a plant is established, arrangements could be made to let down from the catch basins, at points upstream, the accumulated material; this would be carried by the stream to a central basin somewhere within the city limits.

We believe similar impounding basins on a smaller scale might be practicable on Roaring Brook, and that such material, if gathered at a higher elevation, might be flushed to near-by mine workings by gravity.

CITY REFUSE.

Another source of supply of material for flushing purposes would be city ashes and refuse from the streets and catch basins; also material from cellar excavations, grading of streets, parks, etc., which of course would have to be put through a crushing plant and reduced to such a size that it could be handled by flushing. For the proper distribution of the material just mentioned it would be necessary to drill bore holes to the mine workings at convenient points in the city streets and alleys—preferably in the latter, because there would be less inter-

ference with traffic. The necessary water for flushing this material would, of course, be supplied from the central pumping plant on the river or from the Roaring Brook gravity supply.

SAND FROM DISTANT POINTS.

Another important source of supply of material which we believe would be practicable would be sand and loam that the transportation companies should bring in from distant points along their railroads, where it can be most economically procured, in returning empty coal cars. This material would have to be dumped over a suitably arranged hopper and flushed into the mines with culm and other material.

A comparatively cheap and effective means for transportation of flushing material on the city streets to the shallow shafts and bore holes suggested would be to arrange with the traction company to haul the stuff in suitably designed hopper-bottom cars from the central crushing plant during the time of light traffic at night.

We would suggest the establishment of about four crushing plants so designed as to be easily knocked down and moved to other locations. The material to be handled by these plants should be taken from points where grading of humps and hills will result in the improvement of highways, parks, and private or public lands.

In this connection we would refer to the very extensive grading operations carried on in Seattle, Wash. A large section of the business center of that city was regraded mainly by the hydraulic method. Hills 100 feet high were cut or washed away, buildings were shored up or torn down, and the general level of the regraded section was lowered 10 to 30 feet. The material was flushed into Puget Sound by streams of water, and large areas of new land were formed over the low tide marshes along the bay shore. The expense was met by a general city-improvement tax.

PLANS, SPECIFICATIONS, AND COSTS.

The general nature and wide scope of this report necessarily limit us to general plans, specifications, and estimates of cost. The rendering of detailed plans and specifications and of exact estimates of cost can be made only after careful and exact surveys under particularly ascertained conditions; such surveys should be obtained from the engineers who are to be in charge of the execution of the work recommended in this report, in case it shall be entered upon by the authorities. We therefore explain by way of specifications what will be necessary in our opinion, what we recommend to be done to ameliorate the present conditions, and the approximate cost thereof.

We have made careful investigations of the resisting power of the various devices thus far used for supporting the roof at various

places under this city, and also of other devices we were cognizant of or have ourselves originated, but the supporting values of these various devices, as indicated in the tables of tests presented, have convinced us that the method of flushing material into the mines by means of water is the best and only well-tried method.

The method we have originated and experimented upon to some meager extent—that of providing roof support by simultaneously blasting the floor and the roof of the coal mine to form a permanent pillar from the débris resulting from the blasting—is an economical one, and has its advantages for certain special localities where the overburden is light. Still, the amount of compression to which the pillars of this sort would be liable is considerable and the extent of the possible disrupting effect of the heavy blasting upon the strata is unknown. Consequently, much more extended and practical experiments or tests of the method must be made before its value and importance as a roof supporting device can be established.

Therefore, the only method we feel like recommending, after a careful study of the conditions, is the flushing method.

As before mentioned, the best protection for the surface from caves would require the complete filling of the mine openings with culm, sand, or other form of material, and even then there would be more or less subsidence if pillars were removed and filled-in material were substituted. The excessive cost of completely filling the openings, and the tremendous magnitude of the project makes this plan prohibitive.

In our opinion reasonable protection can be afforded by the introduction of artificial pillars of flushed material, reinforcing the natural coal pillars to the extent of relieving them of one-third of the overburden. Such artificial pillars to be located about as follows, reference being had particularly to the plans shown in Plates 1 to 24, which are part of this report.

Owing to the great importance of substantial support for school properties, we would suggest that in each bed mined under any school, for at least 50 feet outside the lot limits, or rather for a distance equal to one-half the depth of a bed below the surface, the openings be flushed full of the best available material. The school properties—being located in all parts of the city, and over widely varying mining conditions—would afford good starting points from which to space the additional artificial pillars necessary for the protection of the surface elsewhere.

Following out the above scheme in systematic order, we would recommend the installation of artificial pillars of flushed sand or flushed culm at each street intersection where the city blocks are of the usual size, about 5 acres, the present coal pillars to remain. In the case of all coal beds of greater depth than 150 feet, such pillars,

if at the block corners, might be sufficiently near together; but for less depth the strata might be too weak to bridge the whole width of a city block, even though the usual coal pillars were left in place. Therefore it would be better, in the latter case, to install pillars in the center of each block also, in which case the pillars should each be about one-half as large as if located at the block corners only.

In locating artificial pillars intermediate between school properties, advantage should be taken of those places already flushed by the coal companies. It will be found that considerable filling of this sort has been done.

The question of the size and consequent cost of artificial piers is approached by us with much hesitation and caution, because, although we have secured considerable valuable information on the subject through the underground investigations we have been making, we know that in the last analysis the size of these piers must be estimated from the results of the testing we have done at the Fritz engineering laboratory at Lehigh University. In view of the great magnitude and importance of the question at stake, we realize that these tests, which are the first of the kind that have ever been made, are very meager and do not constitute a sufficient foundation upon which to base final conclusions.

Therefore we have decided to use a factor of safety of two. In other words, the size of the pillars we have recommended is twice as large as the tests indicate might be necessary. These tests are subject to check by further tests and other data that may be procured later, either through the working out in practice of the recommendations herein made, or otherwise, but which have not been and are not now available to us.

The size of artificial pillars should be determined by the local conditions found at the exact spot chosen upon inspection by the engineer in charge of the work. Subject to the above observations, the horizontal areas of artificial piers of flushed material confined in mine rooms are indicated in detail by the table following.

TABLE 5.—*Horizontal area, in square yards, of artificial mine pillars of confined flushed culm or flushed sand required under various permissible compressions to sustain one-third of the overburden of one city block of five acres, at various depths.*

Ultimate uniform compression permitted.	Depths.					
	25 feet.		50 feet.		100 feet.	
	Culm.	Sand.	Culm.	Sand.	Culm.	Sand.
Per cent.						
3	3,424	800	6,848	1,600	13,696	5,200
5	2,122	452	4,244	904	8,488	1,808
10	848	176	1,696	352	3,392	704
	200 feet.		400 feet.		800 feet.	
3	(a)	6,400	(a)	12,800	(a)	(a)
5	16,976	3,616	(a)	7,232	(a)	14,464
10	6,784	1,408	13,568	2,816	(a)	5,632

a Openings filled.

NOTES.—1. Up to 3 per cent compression, piers of sand and gravel concrete might be only one-half the size of sand piers, but for weights that would produce greater compression they are worthless.
2. One city block of 5 acres covers 24,200 square yards.
3. In fixing upon the amount of compression that might be permitted, consideration should be given to the fact that where several beds are to be filled, the total settlement will be several times as great as for one bed of the average thickness.
4. It will be noted that complete filling with culm is necessary for the compression mentioned at depths of 200 to about 500 feet, whereas for greater depths the compression due to the greater weight would be excessive. Sand, on account of its greater strength, is suitable for filling all beds at all depths under the city of Scranton, and is therefore to be preferred.

The location of bore holes or shafts through which to flush the material must be determined by the engineers in charge of the work. Several of the blocks can be reached from the foot of each bore hole or shaft.

In many of the beds on the west side large areas of the mines are inaccessible, and conditions are of such a character that we are thereby limited to the most general specifications. We would suggest first, that the school properties be taken as starting points, and under each of them, namely, Nos. 13, 43, 12, 29, 32, 32 annex, 14, 31, 16, 17, 18, 19, 41, 21, 40, 24, 22, 23, 25, 26, and 44, artificial piers of flushed material be installed wherever possible, these piers to extend well beyond the lot lines (at least 50 feet outside) in all the beds that have been worked, beginning with the lowest bed; and that when a pillar is built in that bed, the overlying beds be filled in order.

Early attention to schools Nos. 12, 23, and 29 is especially important. In locating the supporting pillars advantage should be taken of the large areas that are caved and closed in the Clark, New County, Big, Rock, and Diamond beds, and of other parts that are already flushed. The best results will be obtained, of course, by flushing the lowest beds first and proceeding upwards, care being taken to locate the new pillar in the upper seam over that already in place in the seam below.

COST OF SUGGESTED PROTECTIVE MEASURES.

The absence of accurate and conclusive data, and the many uncertain factors entering into this general statement make any submitted figures approximate only. Assuming that all the sources of flushing material hereinafter mentioned in the order of their importance and value—first, sand and loam brought from a distance in returning empty coal cars; second, culm from breakers and washeries; third, crushed mine rock, gob, etc.; fourth, culm and silt from Lackawanna River and Roaring Brook; fifth, crushed rock from three or four plants (which might be established by the protective commission)—are utilized in regular and systematic order, and that the methods of procuring water for flushing, etc., as suggested, are put in effect, we would in that case estimate the cost of the measures suggested about as follows:

The necessary plants and machinery for expeditiously excavating and loading the sand and filling material at distant points, and the plants in the city for unloading and transferring the material to the traction company cars for delivery at night to the various flushing points; the building of the dam and pumping stations on the Lackawanna River and the necessary storage dams at various points on the river above the city, for catching surplus sediment during seasons of high water; the dam in Roaring Brook, above the city level; the necessary means to conduct the water to the more elevated parts of the east and south sides; and a portable crushing plant to be located at the flushing points to crush the larger particles of sand, coal ashes, and city refuse that may be delivered and mixed with the flushing, would cost approximately $500,000.

The necessary facilities outlined above for the expeditious and economic handling of material and prosecution of the work having been provided, it is our opinion that artificial piers may be established in various beds at about the cost shown in the following table, using the factor of safety (2) mentioned above.

TABLE 6.—*Approximate cost per foot of coal-bed thickness of artificial mine pillar of confined flushed culm or flushed sand required under various permissible compressions to sustain one-third of the overburden of one city block of five acres, at various depths.*

Ultimate uniform compression permitted.	Cost.					
	Depth, 25 feet.		Depth, 50 feet.		Depth, 100 feet.	
	Culm.	Sand.	Culm.	Sand.	Culm.	Sand.
Per cent.						
3	$286	$266	$572	$532	$1,144	$1,064
5	176	150	352	300	704	600
10	70	60	140	120	280	240
	Depth, 200 feet.		Depth, 400 feet.		Depth, 800 feet.	
3	[a] $2,016	$2,128	(a)	$4,256	(a)	[a] $8,070
5	1,408	1,200	(a)	2,400	(a)	4,300
10	560	480	$1,120	960	(a)	1,920

[a] Filled.

The approximate cost per foot of bed thickness for each acre of complete flushing under schools and elsewhere, to take the place of pillars, if removed, would be:

For culm below level of river	$405
For sand above or below river	1,615

If, in the case of the coal beds 150 feet or more deep, the board of control concludes to be satisfied to relieve the present pillars under the schools of about one-third of the burden they now sustain, the approximate cost of so doing, per foot of bed thickness for each acre thus protected, will be about one-fifth of the cost shown in Table 6, for the same depth, material, and settlement. For example, to relieve the present pillars of the Clark bed, which is about 200 feet deep under the central city and hill sections, of one-third of the weight they now sustain, allowing 5 per cent as ultimate permissible settlement for the coal-bed roof, would cost per foot-acre of coal bed, about $280 for culm flushing, if the piers are below the river level; or $240 for sand flushing, whether above or below the river; and since this coal bed is about 7 feet thick, the total cost of such piers would be about $1,960 and $1,680 per acre, respectively.

The above table is estimated on the supposition that the pillars of flushed culm would be installed only at points that are in coal beds below the level of the river (so the necessity of pumping culm to an elevation above the river would be avoided) and that piers of flushed sand would be installed in coal beds at locations that are above the level of the river, or at any location where such sand pillars would be convenient and not more costly than culm pillars.

It will be noted that there is no large difference in cost between culm or sand. This, of course, is on account of the greater efficiency

of the sand, a less quantity of which is required to give the same supporting power.

It will be apparent that much of this work can be done by the systems of flushing already in service at the several mining plants, and that in order to accomplish the best results in the most economical manner, the plans of the city mine-cave protective commission must be made in harmony with the already established systems of the mining companies. It is manifest that all underground work should be done in cooperation with the coal companies and that the water flushed into the mines must be pumped by the plants already installed, with such additional equipment as may be found necessary.

Therefore, this matter of harmonious plans and procedure between the coal companies, the city, the school authorities, and the public is essential to the successful carrying out of any relief measures that are herein or may be hereafter suggested. It is a fact that should be evident to all that the prosperity of the city and the community is to a large extent dependent upon the coal companies, so that drastic laws or regulations that may curtail the mining of coal will necessarily react on the prosperity of the community, whereas any ameliorating plans or compromises which it may be possible to effect between the city and the mining companies tend to prolong the life of the mining industry in Scranton and vicinity, and should be promoted.

It should, therefore, be the aim of all persons interested in mine-cave protective measures and of the companies operating the mines to adopt plans that will best conserve the welfare of all concerned.

The expenditure for the work would, of course, be distributed over many years, the relief measures being applied at the points most in need of protection and as rapidly as proper arrangements could be effected and the necessary details, surveys, etc., prepared.

For the business-like carrying out of the plans suggested, it is recommended that a protective commission be established, consisting of not less than three nor more than five men representing the city authorities, the school board, and the coal companies; this commission to have full and complete authority for the execution of the plans, after approval by the proper legal action. The commission should employ an engineer as active manager of the work, who should devote all his time to the service.

GENERAL CONCLUSIONS.

In concluding this somewhat lengthy report, we are of the following opinion:

First. Speaking broadly, the surface of the city can be supported by the methods recommended, and at a cost not in any sense prohibitory when considered with relation to the value of the property and the activities for which support is absolutely essential.

Second. Although there are points in the city, as indicated in the detailed report, where at the present time in our judgment there is distinct and immediate danger to life and property, yet the total area immediately threatened constitutes but about 15 per cent of the entire area of the city, and the danger is mainly from workings in surface beds.

Third. On the west side the beds of the middle series are thick and close together and the pillars are not columnized, creating a dangerous situation where the workings have not been closed by previous caves. Particular areas thus threatened can not be definitely specified on account of the inaccessibility of much of the mined-over area. Detailed investigation should be made of the portions of the mines not already closed. Relatively, we do not believe that a large part of the territory mentioned is threatened because so much ground has been already closed by caves.

Special attention is called to the conditions under schools Nos. 13, 23, and 29. They should be attended to promptly.

The beds of the lower series, namely, the three Dunmores, are so thin and so far below the surface that with the usual system of mining we do not think they constitute a serious menace to the improvements on the surface, except along the margin of solid blocks of unmined coal and near the outcrops. In the deep-lying parts of the Dunmore beds we believe these solid blocks should be mined.

Fourth. It would seem, therefore, to be not only the part of wisdom, but absolutely obligatory to commence at once to give support to the points menaced, and thereupon proceed upon a general policy of giving support to the entire area of the city; for it must be borne in mind that with the mining activities that are constantly going on other and additional points of danger are not only liable to, but in all probability will, develop with each passing year—it might almost be said with each passing month.

Fifth. Where the owner of the surface has undoubted right to the support thereof by coal pillars, in our opinion he could permit the removal of such pillars; the value of these would under average conditions pay for such artificial support as we have recommended, assuming that the pillars were mined and the support constructed by the same operating company. This observation, however, is based upon the assumption that in such case the operating company would be one of the large transportation companies, inasmuch as while there might not be a profit in the immediate transaction of mining the pillars and installing the support there would, of course, be a profit to such companies in carrying the coal to market.

Sixth. Culm flushing should be used only in coal beds having light cover, up to 200 to 500 feet, according to the amount of settlement expected. But sand, being four or five times as strong as culm, is better, is suitable for all beds under Scranton and should be preferred.

Seventh. We believe that the conclusions adduced from the tests made, and the calculations and tabulations based thereon, are reasonably reliable; yet we desire to record the opinion that there are conditions existing in the mines to which they might not apply—for instance, in localities where several seams of coal are separated by a thin layer, or layers, of shale and slate, or even sandstone, and the pillars in the several seams are not over one another, and it is proposed reclaiming all or any part of the pillars.

Even though an application of the above tables might appear to fit the conditions, we believe that the only permissible procedure would be to first fill with flushed material all of the openings in the lowest bed of the series and then fill upward until all the beds are filled, care being taken to have the flushed areas over one another. After all of the openings in all of the seams have been filled, the pillars in the uppermost seam may then be attacked; as each pillar is removed, the space should be at once filled. No pillar reclamation should be permitted in any of the other beds until all of the pillars in the upper bed have been removed and the overburden has come to rest on the flushed material; then the pillars in the next lower seam may be attacked and handled in like manner.

NOTES ON SAND FOR MINE FLUSHING IN THE SCRANTON REGION.

By N. H. Darton.

INTRODUCTORY STATEMENT.

This report presents the results of field studies in the vicinity of the city of Scranton, Pa., to find some convenient sources of sand to be used for filling chambers in coal mines under the city. Attention was given only to material that lies at higher altitudes than the workings and might be hauled down grade or transported by water to the mines. Moreover, it was recognized that inasmuch as the final means of transportation underground would be flushing with water the material would have to be in granular condition. The sources of supply are glacial till of various kinds and the rocks of the coal measures or underlying formations. The latter would have to be quarried and crushed; the pebbles and bowlders of the till could be crushed or discarded.

ROCK FOR CRUSHING.

The entire anthracite region is underlain by rocks that contain a large proportion of sandstone suitable for crushing, and can yield an angular sand of great strength. It is estimated that sandstone of moderate hardness can be crushed into coarse sand for $0.50 to $0.60 a ton, including quarrying. This estimate is based on a cost of $1.60 per ton for coal for power.

One of the most conspicuous rocks in the Scranton region is the Pottsville conglomerate. It immediately underlies the coal measures and outcrops in belts of varying width in the mountain slopes on both sides of the coal field. The greater part of this rock is too hard to be cheaply crushed into sand. It is underlain by greenish and gray sandstones, mostly soft, and in places by red shale. These sandstones and the shale can be more easily crushed. The most extensive ledges of sandstone convenient to railroad haulage are in the gorges of Roaring Brook east of Scranton, and of Leggetts Creek, northwest of the city. Along the gorge of Roaring Brook from Moscow to Dunmore there are continuous high ledges, many of which rise 500 to 700 feet above the creek. This gorge is followed by the Erie and the Lackawanna railroads with a heavy down grade into Scranton. There are many localities favorable for the establishment of quarries and crushers, and the possible tonnage of product is practically unlimited. It is certainly sufficient to fill all coal workings

under the city of Scranton. One crushing plant is already in operation by the Nay Aug Stone Co., just below Nay Aug station. However, a large amount of stone is available farther down the gorge and therefore considerably nearer Scranton. Crushed rock from a quarry in this gorge could be loaded directly on empty coal cars and hauled down grade into Scranton.

The sandstones underlying the Pottsville conglomerate in the gorge of Leggetts Run present a thickness of about 800 feet, rising in high walls along the gorge 2 miles northwest of Providence. There is here available a very large amount of sandstone of moderate hardness, admirably located and physically well suited for sand for filling. The product could be hauled down grade on the Lackawanna Railroad or on the trolley line which follows the bottom of the gorge.

The hydraulic transportation of the fine crushed stone to the mine was not especially considered, but both on Roaring Brook and on Leggetts Creek the waters are so impounded that perhaps they are not continuously available for hydraulic work. The sandstones under the Pottsville conglomerate are exposed also in the valley of Meadow Brook in the southern part of Scranton, where they are utilized by the crusher now in operation. This crusher belongs to the Meadow Brook Co. and has a capacity of about 300 tons a day. Crushed stone from the exposures in this vicinity would be handled by the Laurel line and the Erie Railroad; possibly, also, it could be flushed down the bed of Meadow Brook, but the conditions are much less favorable for such tranportation than on Roaring Brook or Leggetts Creek.

There are extensive ledges of the sandstones of the coal measures in the high ridge extending west from Lackawanna River, just east of Holden, where a moderately large amount of gray sandstone is available. Another ledge appears on the north bank of Leggetts Creek, near its mouth. This ledge has been quarried extensively, but the quarry could be extended over 1 or 2 acres to the north. To the northwest it passes under the huge pile of culm from Leggetts Creek colliery. Sandstone ledges outcrop prominently in the high ridge on the east bank of Lackawanna River, a half mile east of Dickson, and a crusher could be established at this place with fair advantage, as the ledges are directly over extensive coal workings.

GLACIAL TILL.

The till left by the great continental glacier extends across northern Pennsylvania, and forms a mantle of irregular thickness and varying composition. In the Scranton region it covers much of the surface to a considerable depth, excepting the mountain slopes and summits, where it is thin or absent. The underlying coal-measure rocks also appear in places along the lower slopes of the

Lackawanna Valley, and near the river there are terraces of later alluvium. Where the till is thick it rises in hummocky ridges that are generally thickly strewn with bowlders. Scranton is built mostly on slopes of till, terraces of rearranged till material, and later beds of sand deposited by Lackawanna River.

The glacial till consists of a mixture of sand, clay, loam, gravel, and bowlders in varying proportion. In the Scranton region the till contains little clay and a predominance of sand, but I saw no extensive deposits of pure sand. Gravel and bowlders exist in all the exposures and their proportion is seldom less than 50 per cent. Some streaks of pure or pebbly sand occur, but they are local and would not yield a large supply. If the sandy till were subjected to washing by hydraulic jets and sluiceways the sand would all be separated from the bowlders. This till, in my opinion, is the best source of sand in the region; it can be removed at many places where the cultural and hydraulic conditions are favorable. One of the most desirable sources of supply would be from street grading, since the result would be both a large volume of sand and a city improvement. The bowlders remaining after the sand had been carried off could be crushed into sand and washed into the sluiceways.

In the northern part of Providence there are several prominent hills or knolls of sandy till which could be leveled to advantage. They lie between Bloom and Keyser Avenues, west of West Market Street; another knoll lies just east of West Market Street, north of Clark Avenue. These knolls rise from 50 to 60 feet above the average grade of the streets and would furnish nearly a half million tons of material. The material contains about 50 per cent of sand; the remainder is gravel that would have to be crushed in order to be utilized for flushing. Two very much larger masses of till lie on the mountain slope a short distance north and west of this area and another extends up the ridge on the north side of Leggetts Creek. Each of these three areas contains about a million tons of sandy till. Similar masses of till lie on the lower slopes of the mountain west of Keyser Creek, the largest one extending to within a few hundred yards of the Hyde Park colliery. There is a rock core to this largest mass, but the till is not less than 50 feet thick, and the indicated total tonnage for this one area is about 15,000,000 tons. The deposit is mostly sandy till with only a small proportion of clay; it averages nearly 50 per cent sand. The remaining material is coarse bowlders, mostly of hard rocks, which might either be crushed into sand or left on the ground after the sand is washed out. There is in this vicinity only a meager supply of water for hydraulicking.

An extensive area of sandy till is just east of the Holden colliery. It underlies land that for the greater part is not covered by buildings,

and has an estimated tonnage of about 5,000,000 tons. The material contains about 50 per cent of sand, with gravel, bowlders of hard rock, and very little clay.

One of the most desirable bodies of sandy till is on the estate of William Miles, just west of Olyphant. The land is not built on and is adjacent to various lines of railroads. A moderate amount of water is available for sluicing in a near-by creek, and water possibly can be had from the river also. The till area measures about 2,000 by 1,500 feet, and the thickness of material available is about 30 feet. These measurements indicate an aggregate of nearly 5,000,000 tons. The proportion of sand is variable, but in places it exceeds 60 per cent. It is being dug to a small extent for sand for local building purposes. There is not sufficient clay in any part of the area to be disadvantageous, and the gravel and bowlders could be crushed, if desired.

ALLUVIUM.

Along the Lackawanna River extend low alluvial terraces, which are underlain by sand that in greater part contains only a small proportion of coarse material. Unfortunately, however, the sand area near Scranton is covered with houses or is held for its value as building lots, so that the sand is not available except at a few points. As the terraces are very low, the tonnage of sand that could be obtained is not great. It is possible that the water of the river could be used for sluicing this material, but because of the great variation in the amount of water available during the different seasons of the year, the conditions are not altogether favorable. The location of the railroads along the river complicates the problem of removing the sand. Doubtless this source of material would not be as advantageous as the sandy till or crushed rock.

RIVER SAND.

The most extensive deposit of sand in the northern anthracite coal basin is under the deep valley of the Susquehanna River from Pittston to Nanticoke. Its width averages 2 miles for a long distance and its thickness varies from 100 to 200 feet in greater part. There are many places where this material could be lifted from the river channel by dredges and loaded on empty coal cars. In the river and harbor work of the United States Engineers office and in Panama Canal excavations sand is dredged from depths of 20 to 40 feet and carried in pipes 1,000 to 2,000 feet at a cost of 3 to 5 cents a cubic yard. The cost of handling sand from the Susquehanna River is a matter for local engineers to determine. The sediment brought down by the river, especially in time of flood, would rapidly refill excavations made by dredging.

APPENDIX.

COMPRESSIVE STRENGTH OF ANTHRACITE COAL.[a]

Owing to the general lack of knowledge among the engineers of the anthracite coal field as to the compressive strength of anthracite coal, and in view of the very important matters relating to the economy of mining of anthracite, which depend directly upon this subject, the Scranton Engineers' Club, in July, 1900, appointed a committee to make a general investigation of the compressive strength of anthracite coal, having reference particularly to the northern anthracite field. This table contains the results of the efforts of that committee, in a condensed form. The committee sent circular letters to the various anthracite operators in the northern field, requesting them to contribute to the efforts of the committee by sending samples in triplicate to be tested. These samples were requested in three sizes, viz.:

Two inches square on the base by 1 inch high, indicated in the table as "1."

Two inches square on the base by 2 inches high, indicated in the table as "2."

Two inches square on the base by 4 inches high, indicated in the table as "4."

These samples were requested to be prepared in each case with the base parallel to the bedding plane of the coal seam, and the height at right angles thereto.

Generous responses to this circular letter were received in the form of some 425 samples for testing, a few of which were defective and not tested. These samples were then divided and sent to the following colleges for testing, the professors named very kindly offering to assist the committee by making the tests:

To Prof. R. C. Carpenter, of the department of experimental engineering, Sibley College, Cornell University, Ithaca, N. Y., 133 samples.

To Prof. Mansfield Merriman, professor of civil engineering, Lehigh University, South Bethlehem, Pa., 177 samples.

To Prof. Louis E. Reber, dean of the school of engineering, Pennsylvania State College, State College, Pa., 113 samples.

After these samples were tested and the results returned to the committee, they were tabulated in a detailed way, forming an immense table, of which this accompanying table is a condensation. The following description of it is given, that the reader may the better understand it:

1. The collieries from which the tests were taken are arranged in the column on the left, in order, according to the location of the collieries, beginning at the northerly end of the region near Forest City and ending with the southermost collieries from which tests were received, at Williamstown and Lykens, in the southern coal field.

2. The coal beds are arranged at the top of the table in the order of their occurrence in the measures, the highest beds being at the left, and the lowest beds at the right. Where local names for the beds differ from the general names, their local names are inserted in the body of the table.

3. The tests are arranged in vertical double columns under the several coal seams, and each test is placed in the column under its respective coal bed and in the horizontal line opposite the colliery from which it was taken.

4. Results given in this table are in pounds avoirdupois per square inch of horizontal area.

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[a] Printed by permission.

5. The items given in the columns under the coal double-bed headings are the "First crack," indicating the pressure in pounds per square inch required to produce the first crack in the sample. In other words it is the pressure which would cause the coal of the same quality as the sample to begin squeezing. The items under "Maximum load" in each case indicate the pressure in pounds per square inch at at which the sample crushed. The items under the head of "No. of tests" indicate the number of tests taken from the respective beds in the several collieries, the average of these tests being represented by the figures in the table.

6. The horizontal line headed "General average" contains the average of all the tests under the respective coal beds as indicated.

The next horizontal line under "General average" indicates the percentage of the maximum load which is represented by the pressure necessary to produce the first crack, or the squeezing pressure. And the second horizontal line under the general average shows the percentage which tests 2 and 4 bear to test 1 in each case.

The grand average, or net result, is contained under a separate heading, and indicates generally the average squeezing and crushing strength as shown by the samples tested. The tests from the several coal fields are tabulated separately, and clearly show the superior strength of the harder coals and the weakness of the softer.

7. From an inspection of this table, the following results appear to apply, approximately:

That the squeezing strength of a mine pillar whose width is twice its height is about 3,000 pounds to the square inch, and the crushing strength about 6,000 pounds per square inch, or, approximately, twice as much. And in general, other things being equal, the crushing strength of mine pillars would vary inversely as the square root of the thickness of the bed.

The same general rule apparently holds true, also, for the squeezing strength in all cases where the height of the pillar is less than its width. In tall pillars having a height greater than their width, the squeezing strength apparently remains nearly constant, while the crushing strength continues to diminish with height according to the above rule.

WM. GRIFFITH, *Chairman*.	HARRY E. YEWENS,
J. H. FISHER,	H. H. STOEK,
MORGAN DAVIS, JR.	J. T. BEARD,

Coal-test Committee, Scranton Engineers' Club.

Compressive strength of anthracite coal.

NORTHERN COAL FIELD.

Collieries.	Height of sample.[a]	Kidney.[b] First crack.	Kidney. Max. load.	Kidney. No. of tests.	Olyphant No. 2, Hillman. First crack.	Olyphant No. 2, Hillman. Max. load.	Olyphant No. 2, Hillman. No. of tests.	Diamond. First crack.	Diamond. Max. load.	Diamond. No. of tests.	Rock. First crack.	Rock. Max. load.	Rock. No. of tests.	Big Baltimore. First crack.	Big Baltimore. Max. load.	Big Baltimore. No. of tests.
Vandling[b]	1															
	2															
	4															
														Mills.		
Coal Brook	1													2,901	6,187	3
	2													986	3,150	3
	4													1,200	2,079	3
Erie	1															
	2															
	4															
														Grassy.		
Jermyn, D. & H.	1													5,410	9,891	3
	2													2,541	7,415	3
	4													5,053	6,653	3
Olyphant	1				1,825	6,026	3	2,325	5,176	2	1,822	6,316	3	2,792	6,720	3
	2				1,131	4,020	3	4,485	7,301	2	1,167	2,785	2	1,628	3,614	3
	4							1,460	3,233	3	1,536	2,565	2	3,017	3,741	2
Marvine	1							2,868	4,674	3				4,764	4,765	3
	2							1,014	1,309	3				802	3,947	3
	4							1,398	1,828	3				1,895	2,741	3

Collieries.	Height of sample.[a]	New County. First crack.	New County. Max. load.	New County. No. of tests.	Clark Ross—Arch. First crack.	Clark Ross—Arch. Max. load.	Clark Ross—Arch. No. of tests.	Dunmore Red Ash. First crack.	Dunmore Red Ash. Max. load.	Dunmore Red Ash. No. of tests.	Dunmore No. 2. First crack.	Dunmore No. 2. Max. load.	Dunmore No. 2. No. of tests.	Dunmore No. 3. First crack.	Dunmore No. 3. Max. load.	Dunmore No. 3. No. of tests.	Grand average. First crack.	Grand average. Max. load.	Grand average. No. of tests.
		Top coal.			Bottom coal.														
Vandling[b]	1	2,971	5,663	2	1,475	8,749	3	4,423	7,531	3									
	2	2,762	4,425	2	2,569	5,239	3	2,113	7,687	3									
	4	1,800	2,787	2	1,410	2,012	3	1,975	3,318	3									
Coal Brook	1																		
	2																		
	4																		
		Three-foot.																	
Erie	1	3,000	8,067	1	1,500	3,425	1												
	2	1,500	2,182	1	1,525	1,975	1												
	4	1,250	1,780	1	455	1,872	1												
Jermyn, D. & H.	1				2,564	5,619	3												
	2				4,041	5,841	3												
	4				1,848	2,332	3												
Olyphant	1																		
	2																		
	4																		
Marvine	1				4,781	6,963	3												
	2				2,704	5,275	3												
	4				1,562	1,600	3												

[a] Test samples 2 inches square by 1 inch high indicated by 1. Test samples 2 inches square by 2 inches high indicated by 2. Test samples 2 inches square by 4 inches high indicated by 4.

[b] The coal beds are arranged in order as they occur, that is, highest on left and lowest on right. The collieries are arranged in order as located, that is, northern at top and southern at bottom. All tests in pounds per square inch.

Compressive strength of anthracite coal—Continued.

NORTHERN COAL FIELD—Continued.

Collieries.	Height of sample.	Kidney.			Olyphant No. 2. Hillman.			Diamond.			Rock.			Big Baltimore.		
		First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.
D. & H., Scranton	1							2,331	3,260	2	2,319	4,266	2			
	2							1,454	3,011	2	1,811	3,221	2			
	4							1,530	2,578	2	1,346	1,630	2			
Leggetts Creek	1															
	2															
	4															
Dickson	1													3,685	6,381	3
	2													3,900	5,426	3
	4													1,657	1,819	2
Cayuga	1										500	3,200	1			
	2										250	1,125	1			
	4										970	1,625	1			
					Four-foot.											
Von Storch	1				5,881	6,426	3	2,500	5,000	1	2,875	5,500	1			
	2				2,836	4,102	3	1,500	3,500	1	1,820	4,125	1			
	4				1,930	2,343	3	2,500	3,200	1	3,000	3,941	1			
D., L. & W., Scranton	1													5,000	7,000	1
	2													875	2,250	1
	4													520	645	1
Bellevue	1															
	2															
	4															
Holden	1										2,675	4,575	1			
	2										1,132	4,165	1			
	4										930	1,160	1			

Collieries.	Height of sample.	New County.			Clark Ross—Arch.			Dunmore Red Ash.			Dunmore No. 2.			Dunmore No. 3.			Grand average.		
		First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.
D. & H., Scranton	1				2,854	6,107	2												
	2				2,545	4,251	2												
	4				2,382	3,941	2												
Leggetts Creek	1	1,869	4,882	3															
	2	1,662	2,784	2															
	4	1,279	2,832	3															
Dickson	1				4,113	6,274	3	2,343	3,228	3	3,821	4,821	3						
	2				1,575	3,001	3	1,668	4,330	3									
	4				865	1,720	3	1,650	2,195	3									
Cayuga	1				1,500	3,500	1												
	2				1,375	3,250	1												
	4				1,875	3,215	1												
Von Storch	1				2,750	5,462	1												
	2				2,250	3,960	1												
	4				2,250	3,045	1												
D., L. & W., Scranton	1	2,000	4,000	1															
	2	1,735	1,947	1															
	4	1,537	2,120	1															
Bellevue	1	3,500	6,875	1	2,000	5,700	1	2,500	4,500	1									
	2	3,125	4,000	1	3,625	4,990	1	2,375	3,625	1									
	4	4,315	4,625	1	1,705	2,000	1	1,500	2,000	1									
Holden	1	2,000	8,970	1	2,137	4,890	1												
	2	1,800	1,800	1	2,000	3,500	1												
	4				1,795	4,125	1												

Compressive strength of anthracite coal—Continued.

Collieries.	Height of sample.	Kidney.			Olyphant No. 2, Hillman.			Diamond.			Rock.			Big Baltimore.			New County.			Clark Ross Arch.			Dunmore Red Ash.			Dunmore No. 2.			Dunmore No. 3.			Grand average.		
		First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.	First crack.	Max. load.	No. of tests.
EASTERN MIDDLE FIELD.																																		
														Mammoth.						Wharton.			Buck Mt.											
Hazleton No. 5	1													5,000	6,825	1				3,500	10,525	1	7,000	10,962	1									
	2													2,830	3,547	1				4,500	5,400	1	5,000	5,000	1									
	4													1,375	1,375	1				4,000	5,990	1	5,000	3,375	1									
Hazleton No. 1	1																			1,750	5,200	2	5,488	6,528	2									
	2																			1,500	3,000	1	3,113	3,600	2									
	4																			3,057	2,170	2	3,752	4,838	2									
General average	1													5,000	6,825	1				4,000	6,975	3	5,992	8,053	3							4,996	7,417	7
	2													2,830	3,547	1				3,000	3,700	2	3,742	4,066	3							3,343	3,857	6
	4													1,375	1,375	1				3,371	4,110	3	4,135	4,347	3							3,413	3,821	7
WESTERN MIDDLE FIELD.																																		
														Mammoth.						Seven foot.			Buck Mt.											
Packer No. 3	1													3,000	9,892	1				1,552	9,500	1	4,460	6,500	1							3,001	8,681	3
	2													895	4,000	1				500	4,497	1	968	2,000	1							788	3,499	3
	4													1,945	2,500	1				1,370	3,000	1	1,005	1,842	1							1,440	2,447	3
SOUTHERN FIELD.																																		
														No. 9¼ White Ash.			No. 9 White Ash.			No. 7 White Ash.			White's Vein.			Lykens Valley.			Little Lykens Valley.					
														1,442	3,636	2	2,063	4,509	2	897	3,571	2												
														1,087	2,191	2	1,753	3,219	2	860	1,596	2												
														1,516	2,152	2	841	1,150	2	1,361	3,127	2												
																							642	4,013	2	726	4,131	2	976	3,025	2	1,124	3,814	12
																							1,175	2,120	2	966	2,937	2	704	1,198	2	1,099	2,377	12
																							1,231	1,612	2	1,246	2,262	2	736	911	2	963	1,509	12
																																		416

COMPRESSIVE STRENGTH OF MATERIALS FOR ROOF SUPPORT.

A series of tests of various kinds of materials for supporting the roof in mine workings was made in the Fritz Engineering Laboratory at Lehigh University. The results are given in the following report:

SOUTH BETHLEHEM, PA., *January 26, 1911.*

Messrs. WILLIAM GRIFFITH and ELI T. CONNER,

Scranton, Pa.

GENTLEMEN: I beg leave to state that we have concluded the series of tests on the bearing power of materials used in sustaining the roofs of mines, and beg leave to report as follows.

With the exception of a small quantity of sand, all of the materials which we tested were received from you, there being one carload which you sent us from the anthracite coal-mining district. The detailed descriptions of the various tests follow:

TEST NO. 1.

This test consisted of crushing a pillar made of mine rock, the four sides of which were laid vertically and then filled with stone of various sizes packed in by hand so as to make a pillar of loose stones without mortar of any kind. This pillar was 5 feet long, 2 feet 4 inches wide, and 18 inches high. It was laid directly on the bedplate of the testing machine and under three steel beams which were later used in applying the load over the entire top surface of the pillar. The stone used was slate, bony coal, and fire clay. The load on this pillar was applied in increments until a maximum pressure of 489,150 pounds was reached. The following table shows the loading at the different stages of the tests, together with the deflections caused by these loads. You will notice that when the total load was 489,150 pounds (approximately 42,000 pounds per square foot) the maximum compression amounted to 5.3 inches.

TEST NO. 2.

Loads and settlements of a rectangular pillar of mine rock.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
4,950	....	78,625	2.21	260,450	3.95
18,550	0.52	104,050	2.74	326,450	4.32
33,750	.97	130,350	3.15	396,940	4.83
46,350	1.40	233,200	3.75	489,150	5.26
63,025	1.81				

This test consisted in crushing a timber crib made of four layers of round timbers which were about 5 inches in diameter and were laid log-house fashion. Each of two of the layers consisted of two of those round timbers 5 feet 4 inches in length and each of the other two layers consisted of three round timbers 2 feet 8 inches in length. The spaces between these timbers were filled with slate, bony coal, and fire clay, and the crib was then filled with small stones shoveled in; the whole resulting in a timber crib 5 feet 4 inches in length, 2 feet 8 inches wide, and 23½ inches high. The load was applied in increments as shown by the following table. The maximum load reached 900,000 pounds and the maximum settlement was 7.1 inches.

Loads and settlements of a timber crib filled with mine rock.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
5,250	....	120,000	2.13	463,000	4.86
10,550	0.49	140,000	2.33	506,000	5.23
20,000	.78	179,800	2.72	604,000	5.80
30,000	1.02	220,000	3.09	669,000	6.10
40,200	1.21	260,000	3.44	728,600	6.38
60,200	1.48	310,000	3.80	780,000	6.71
80,400	1.74	370,000	4.17	800,000	6.87
100,000	1.96	413,000	....	900,000	7.08

TEST NO. 3.

This test consisted of crushing a circular pillar 28 inches in diameter and 14½ inches high, made of slate arranged so that the outer surface was fairly smooth, the spaces between the stones and the interior of the pillar being filled with small stones. The load was applied in increments as shown in the following table, the maximum load being 361,000 pounds, with a corresponding settlement of 4½ inches.

Loads and settlements of a circular pillar of mine rock.

Loads	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
4,000	....	71,200	1.29	195,400	3.15
20,000	0.19	98,000	1.48	238,500	3.69
37,000	.65	127,000	1.72	276,000	4.05
51,000	.75	150,000	2.50	361,600	4.51
60,200	1.08	183,000	2.82		

After tests Nos. 1, 2, and 3 the stones were found to be very badly crushed, many having been reduced almost to a powder, especially those immediately under the load.

TEST NO. 4.

This test consisted in loading a pile of broken stones and observing the settlement caused by the loading. The stone used was crushed sandstone which would pass through a ring 1¾ inches in diameter; it had 40 per cent voids, but under the bearing plate on which the load was applied the voids were filled with small broken stones so as to get a secure bearing. The pile of stone was 25 inches wide, 9½ inches high, 2 feet 10 inches long on the top, and 4 feet 5 inches long on the bottom. The load was applied on a cast-iron bearing plate 20 inches square which rested on the top of the pile of stones. The following table gives the loads and the settlement. The maximum load reached was 581,000 pounds, and the maximum settlement was 4.4 inches:

Loads and settlements of a pile of crushed sandstone.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
1,400	....	44,000	1.73	292,000	3.73
2,450	....	81,400	2.38	437,000	4.10
21,000	0.87	141,700	2.97	581,000	4.36

After the test many of the stones were found reduced practically to a powder. The stones under the bearing plate were greatly disintegrated and the plate was pressed downward into the stones. At the ends the pile moved outward as the load was applied, but on the sides the pile was confined by timbers which prevented lateral movement.

TEST NO. 5.

This test consisted in crushing a pile of broken sandstone of various sizes up to pieces as large as a man's head. Small stones were placed under the bearing plate. The stones were confined on the sides but were free on the ends and were not laid in any order. The pile was 25 inches wide and $11\frac{1}{4}$ inches high; its length was 3 feet 8 inches on top and 5 feet at the bottom. The load was applied by a cast-iron bearing plate on the top of the pile, the plate being 20 inches square. The following table gives the loads and settlements. The maximum load was 417,000 pounds and the maximum settlement was 4.6 inches.

Loads and settlements of a pile of broken sandstone.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
6,500	....	50,000	1.06	194,300	3.21
21,000	0.32	72,500	1.54	266,000	3.74
25,000	.46	155,500	2.35	365,000	4.31
31,500	.61	164,400	2.66	417,000	4.61
33,000	.69				

TEST NO. 6.

This test consisted of applying a load to a pile of river sand by means of a 20 by 20 inch bearing plate. The pile was 8 inches deep, 2 feet 6 inches long on top, and 4 feet 2 inches long on the bottom, had a width of 25 inches, and was confined on the sides but not on the ends. The maximum load reached was 600,000 pounds, and the maximum settlement was 5 inches.

TEST NO. 7.

This test consisted in crushing a pile of broken sandstone, the pile having 40 per cent voids and being of sizes that would pass through a ring $1\frac{3}{4}$ inches in diameter, mixed with river sand in proportions of ten volumes of the broken stone and four volumes of sand. The pile was $10\frac{1}{4}$ inches in depth, 25 inches wide, 2 feet 5 inches long on top, and 4 feet 6 inches long at the bottom; it was confined on the sides but not on the ends. The load was applied on top of the pile through a 20 by 20 inch bearing plate. The following table shows the loads and settlements. The maximum load was 800,000 pounds and the maximum settlement was 4.7 inches.

Loads and settlements of a pile of broken stone and sand.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
2,550	....	100,000	2.41	488,000	4.13
13,000	0.67	180,000	3.02	640,000	4.43
27,300	1.27	249,700	3.39	8001000	4.69
52,300	1.82	337,600	3.73		

TEST NO. 8.

In this test a cast-iron cylinder was filled with coal culm flushed in with water. A piston was then placed on top of the culm and the whole was allowed to stand on a boiler for two days; the cylinder was then placed in the testing machine and pressure was applied to the piston, which in turn communicated the pressure to the culm within the cylinder. The inside dimensions of the cylinder were as follows: Diameter, $6\frac{7}{8}$ inches; depth, $10\frac{7}{8}$ inches. The depth of the culm in the cylinder was 10 inches. The pressure was applied to the piston and the culm was compressed until the settlement reached 2.7 inches under a load of 200,000 pounds. This load corresponds to a pressure of 6,150 pounds per square inch or 443 short tons per square foot. The loads and settlements are given in the following table:

Loads and settlements of wet coal culm confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	10,100	0.66	55,400	1.82
1,100	0.10	12,100	.76	65,000	1.94
2,100	.19	14,100	.85	75,000	2.04
3,100	.27	16,100	.93	85,400	2.13
4,100	.32	18,100	1.01	95,000	2.21
5,100	.36	20,100	1.07	106,300	2.32
6,100	....	25,100	1.22	124,670	2.40
7,100	.43	30,100	1.34	150,000	2.44
8,100	.58	35,100	1.45	200,000	2.73
9,100	.63	45,000	1.66		

TEST NO. 9.

This test consisted in applying pressure to the piston of a cast-iron cylinder in the same manner as in test No. 8, but the cylinder was filled with broken dry sandstone instead of coal culm. This broken sandstone had 40 per cent voids, and the pieces would all pass through a ring $1\frac{3}{4}$ inches in diameter. The cylinder was filled to the top, giving a depth of stone of $10\frac{7}{16}$ inches. The maximum load applied was 300,000 pounds, which caused a settlement of $3\frac{1}{2}$ inches, or 9,200 pounds per square inch. As a result of the test, the stone was completely crushed and compressed into the iron cylinder so that it had to be cut out with a chisel. The loads and settlements for this test follow:

Loads and settlements of broken sandstone confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	16,000	1.79	75,000	2.91
2,000	0.46	18,000	1.89	100,000	3.07
4,000	.72	20,000	1.94	125,000	3.18
6,000	1.10	25,000	2.15	150,000	3.28
8,000	1.30	30,000	2.32	175,000	3.35
10,000	1.43	35,000	2.42	225,000	3.51
12,000	1.56	40,000	2.52	275,000	3.55
14,000	1.69	50,000	2.67	300,000	3.56

TEST NO. 12.

This test was similar to test No. 8 except that the cylinder filled with the culm was allowed to stand, with the piston removed, for eight days over a boiler. The culm was 9 inches deep in the cylinder, and the pressure was applied to the piston until the settlement reached 3 inches under a load of 300,000 pounds. This load corresponds to a pressure of 9,200 pounds per square inch. Although the culm had been drying for eight days, there was considerable water in it; the water was squeezed out during the test. The loads and settlements for this test follow.

Loads and settlements of damp culm confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
500	....	20,000	1.216	150,000	2.631
1,000	0.057	30,000	1.501	200,000	2.762
2,000	.175	40,000	1.708	250,000	2.876
5,000	.452	50,000	1.871	300,000	2.999
10,000	.786	75,000	2.168		
15,000	1.025	100,000	2.373		

TEST NO. 13.

This test was exactly similar to test No. 8, except that the cast-iron cylinder was filled with dry Delaware River sand; the sand was placed in the cylinder and settled by shaking until it was flush with the top. The load was then applied to the piston until a maximum pressure of 300,000 pounds, with a corresponding settlement of 3.4 inches, was reached. The table showing loads and settlements follows.

Loads and settlements of dry Delaware River sand confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	20,000	1.22	150,000	2.75
500	0.13	30,000	1.46	175,000	2.89
1,000	.25	40,000	1.66	200,000	3.01
2,000	.41	50,000	1.83	250,000	3.20
5,000	.65	75,000	2.15	300,000	3.35
10,000	.89	100,000	2.39		
15,000	1.07	125,000	2.59		

TEST NO. 10.

This test consisted in applying pressure to the piston of the cylinder in the same manner as in test No. 9; the broken sandstone had 40 per cent voids; the pieces would all pass through a ring $1\frac{3}{4}$ inches in diameter, and all voids were filled with river sand. The cylinder was filled to the top, giving the mixture of stone and sand a depth of $10\frac{7}{16}$ inches. The maximum load applied was 300,000 pounds, or 9,200 pounds per square inch, which corresponded to a settlement of 2.4 inches. As a result of the test the stone was completely crushed and compacted in the iron cylinder. Loads and settlements for the test follow.

Loads and settlements of a mixture of broken sandstone and river sand confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	10,000	1.01	75,000	1.83
1,000	0.25	15,000	1.16	100,000	1.95
2,000	.46	20,000	1.27	150,000	2.12
4,000	.66	30,000	1.43	200,000	2.25
6,000	.84	40,000	1.55	250,000	2.34
8,000	.95	50,000	1.65	300,000	2.42

TEST NO. 11.

This test consisted in applying a pressure to the piston of the cylinder in the same manner as in test No. 9; but cinders, formed by burning anthracite coal under boilers, were used in the cylinder instead of culm. The cylinder was filled to the top with the cinders, which had 64 per cent voids. The maximum load applied was 300,000 pounds, or 9,200 pounds per square inch, corresponding to a settlement of 5.3 inches. The loads and settlements for this test follow:

Loads and settlements for anthracite-coal cinders confined in a cast-iron cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	....	10,000	2.85	100,000	4.74
700	0.45	14,000	3.23	150,000	4.98
1,400	.93	20,000	3.55	200,000	5.14
2,400	1.38	34,100	3.99	250,000	5.25
4,000	1.89	60,000	4.41	300,000	5.33
6,000	2.34				

TEST NO. 14.

Pure sand was flushed into a cylinder. The sand was allowed to dry for a period of 48 hours. The top of the sand was 1½ inches below the top of the cylinder.

The following are the results of the test:

Loads and tests of Delaware River sand confined in a cylinder.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
650	....	40,000	0.56	160,000	1.39
2,000	0.06	50,000	.67	175,000	1.51
5,000	.12	75,000	.90	200,000	1.60
10,000	[a].21	100,000	1.00	250,000	1.79
20,000	.31	125,000	1.25	300,000	1.93
30,000	.46				

[a] Water appeared on surface of sand.

TEST NO. 15.

A pile of blue coal measures sandstone, in pieces 3 inches to 6 inches square, the pile measuring 20½ inches wide, 3 feet 3 inches long on the top, and 9 inches deep, voids on top filled with a small quantity of broken Potsdam sandstone for bearing. On the sides the 3 feet 3 inches dimension was confined by 6-inch by 8-inch timbers; the base plate of the machine and the I beams confined the material on the top and bottom. On the ends the material was free to move outward, but in the test there was very little movement at the ends. The loads were applied to the top of the pile in increments, and the maximum load reached was 600,000 pounds.

The following table gives the loads and the settlements corresponding thereto:

Table of loads and settlements.

Loads.	Settlements.	Loads.	Settlements.	Loads.	Settlements.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
3,100	....	80,000	0.81	232,000	1.56
6,000	....	90,000	.88	305,000	1.57
8,000	0.06	100,000	.93	321,700	1.67
10,000	.12	110,000	.95	352,000	1.76
15,000	.18	120,000	1.00	375,000	1.82
20,000	.255	140,000	1.06	395,000	1.89
25,000	.325	162,000	1.15	425,000	1.97
30,000	.375	180,200	1.25	460,000	2.05
41,000	.48	201,500	1.30	500,000	2.10
50,000	.55	286,000	1.38	525,000	2.17
60,000	.62	240,000	1.43	554,000	2.25
70,000	.73	260,000	1.48	600,000	[a] 2.43

[a] This settlement is equivalent to 27 per cent.

Yours, very truly,

FRANK P. MCKIBBEN.